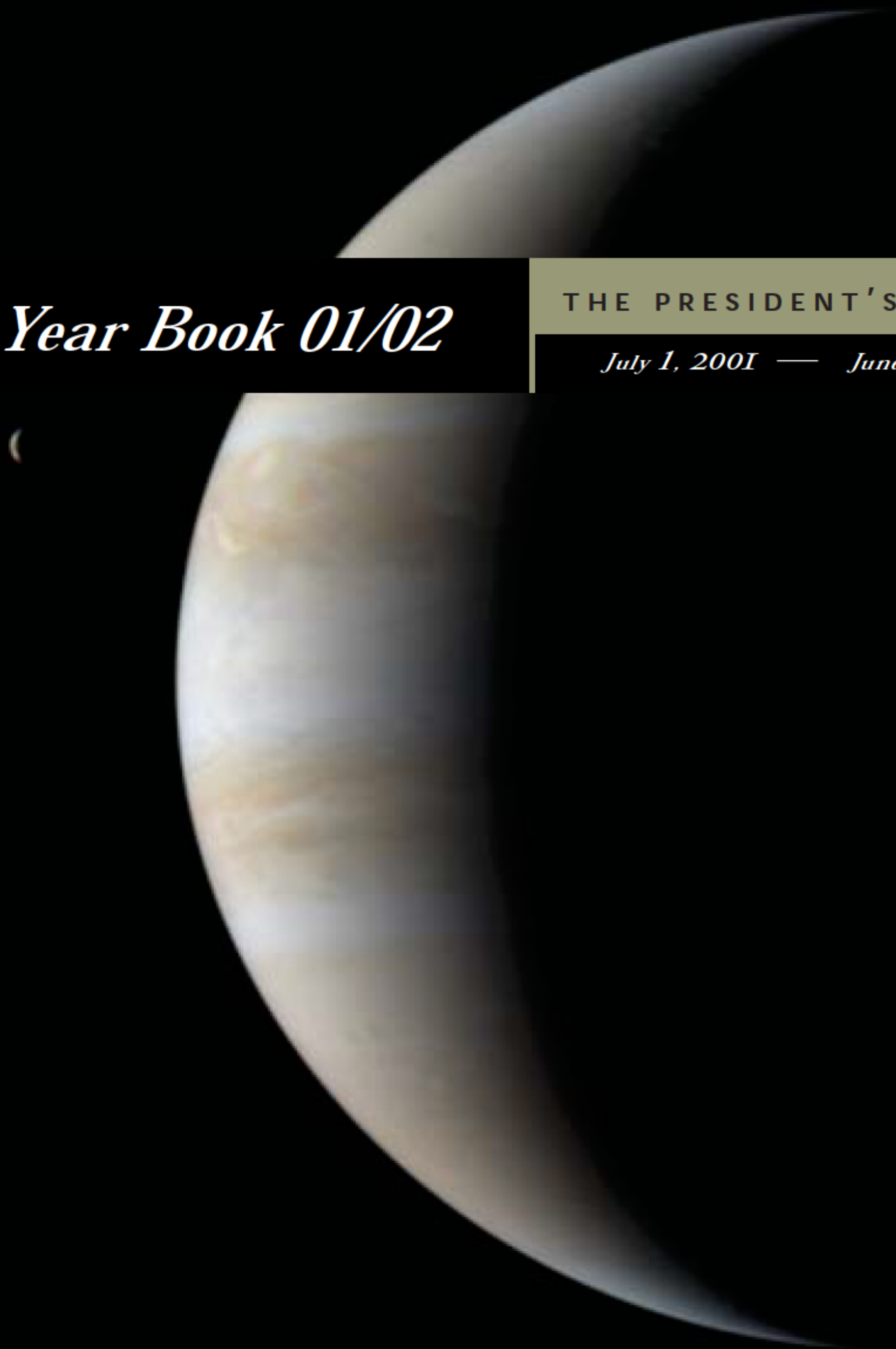
Year Book 01/02

THE PRESIDENT'S REPORT

July 1, 2001 — June 30, 2002



CARNEGIE INSTITUTION
OF WASHINGTON

ABOUT CARNEGIE

. . . TO ENCOURAGE, IN THE BROADEST AND MOST LIBERAL MANNER, INVESTIGATION, RESEARCH, AND DISCOVERY, AND THE APPLICATION OF KNOWLEDGE TO THE IMPROVEMENT OF MANKIND . . .

The Carnegie Institution of Washington was incorporated with these words in 1902 by its founder, Andrew Carnegie. Since then, the institution has remained true to its mission. At six research departments across the country, the scientific staff and a constantly changing roster of students, postdoctoral fellows, and visiting investigators tackle fundamental questions on the frontiers of biology, earth sciences, and astronomy.

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Former Presidents & Trustees


GENES & GENOMES

TAKING STOCK

Fifteen years is a significant span for any individual or institution. When the time is centered on science, it can seem like a lifetime. Each new day brings new and refreshing scientific ideas and information. The accelerating pace is spurred by old-fashioned human curiosity and new-fashioned technology. Like the very first chip of glass to shift in a kaleidoscope, a novel scientific observation or insight can initiate a new pattern. A strong institution must be able to recognize and pursue new patterns. To assess an institution's agility requires examining the past. As scientists, we always prefer to look forward, but there are times when looking back and taking stock are appropriate. This, the occasion of the 15th and final commentary I will write as president of the Carnegie Institution, is one of those times.

New Organizational Patterns

The refreshing discoveries made in the Carnegie departments during these past 15 years have been an inspiring spectacle. Sustaining the effort demanded that the institution's trustees and administration keep pace by facilitating the changing science.

The board of trustees imparts coherence to the institution's vision (Fig. 1). It is a collaborator in all that Carnegie accomplishes. From my own service on boards and other observations, I know that Carnegie's trustees are unique. They are clear-minded about our purposes and rigorous in their evaluations. Their unbridled enthusiasm for new ventures translates into a willingness to take both financial and scientific risks. Remarkably, this is true of both longtime dedicated trustees and the new people who joined the board in recent years. Science has a debt to each of them. Through their attention and generosity, they have assured our ability to lead. Perhaps the others will be forgiving if I single out the recent chairmen for their extraordinary collegial support and friendship: William Hewlett, Richard Heckert, and Thomas Urban.

By the end of the 1980s, the value of Carnegie's endowment was static, in part because of poorly performing financial markets. Another cause of the weakness was the drain on the endowment from the commitment to use endowment funds to build new facilities at Broad Branch Road for the co-location of the Department of Terrestrial Magnetism (DTM) and the Geophysical Laboratory (GL). Improvement began with the arrival of John Lively as director of administration and finance. Lively's wise and dedicated commitment to this ever-changing institution is captured in his frequent remark, "At Carnegie, you never do the same thing twice."

One of the first things Lively did after he arrived in 1990 was to establish policies that would put the institution on a sound financial footing. The goal was to assure that we could provide for the substantial scientific independence that makes Carnegie unique. To revive the endowment's prospects, expenditures of Carnegie funds were decreased and then held steady for three years. The success of the effort depended on the remarkably supportive cooperation of the department directors with the imposed stringency. In fiscal year 1994-1995, the draw from the endowment began to increase in a calculated manner. The aim then was, and is now, to keep the annual draw for operating expenses below about 5 percent of the endowment value. This frugality paid off especially well in the

Left: Portrait of Maxine F. Singer, president of the Carnegie Institution of Washington, 1988 to 2002. (Portrait by Jon R. Friedman.)

Fig. 1. Members of the board of trustees posed for this picture during the December 2002 meetings. Back row, standing (from left): Robert Seamans, Jr., Stephen Fodor, David Greenewalt, Suzanne Nora Johnson, Robert Goelet, Tom Cori, David Swensen, Sidney Weinberg, Jr., Daniel Belin, Deborah Rose, William Gayden, John Crawford, John Diebold, Charles Townes, Jaylee Mead, Christopher Stone, Steven McKnight. Front row, seated (from left): Bruce Ferguson, Michael Gellert, Richard Meserve, Carnegie president Maxine Singer, Tom Urban, Philip Abelson. (Courtesy Richard Holden Photography.)

late 1990s, when the endowment began to produce substantial returns as a consequence of the rising financial markets and the intelligent if unconventional investment decisions of the trustees' finance committee under the leadership of David Swensen. The wisdom of those decisions was especially apparent in the positive investment returns in fiscal years 2000-2001 and 2001-2002, when most endowments suffered serious losses. The numbers speak for themselves: in fiscal year 1990-1991 we spent \$14.7 million, or 6.5 percent, of an endowment of \$225.9 million, while in 2001-2002 we spent \$25.7 million, or 5.1 percent, of an endowment of \$501.8 million. Today, this fine financial position is again challenged by discouraging financial markets. The institution will have to exercise discipline and intelligence to sustain its resources and programs.

An important consequence of our improved financial condition is the effort, at the urging of the trustees, to bring compensation for scientific Staff Members more in line with the practices of institutions with which we compete for faculty. Although we have not yet reached our goal, average salaries for Staff Members have increased more than 50 percent in the last six years. We have been able to renew the institution's scientific staff with outstanding new scientific talent while keeping the number of Staff Members constant. More than a third of the present Staff Members arrived during the past 10 years. And the majority of those who retired in that time continue as productive members of their departmental communities. Both the average and median ages of the Staff Members are virtually the same in 2002 as they were in 1992; both were 51 in 1992 and are now 50.

New Funds and Facilities

The endowment, healthy as it now is, cannot sustain the operating budget necessary for the scope of Carnegie work. Neither can it provide fully for

the new and refurbished facilities and instruments required for excellent and original research. Two additional sources contribute essential resources: federal grants and philanthropic donations.

Since fiscal year 1998-1999, federal grants have averaged about $13 million a year, compared with $3.9 million in 1990-1991. This growth reflects the excellence of the proposals put forth by Carnegie scientists, the availability of federal research funds, and the aggressive pursuit of grants, particularly by the most recently appointed Staff Members. As students and postdoctoral fellows in universities, these new scientists learned that reliance on federal funds is a norm. This attitude differs markedly from the expectations of senior Carnegie people who, in view of earlier institutional traditions and commitments, eschewed federal support to varying extents. The rationale for the earlier traditions is still with us: the independence of Carnegie research and our ability to open new areas of inquiry require a degree of freedom from federal programs and the biases of peer review. In recent years, federal grants represented about a third of the operating budget, a reasonable balance between independence and essential external support (see President's Commentary, Year Book 1999-2000). However, at the end of this past fiscal year (2001-2002), we discovered that federal grants had grown such that they represent over half of the operating expenses. We can only applaud this achievement. A subtler consideration is to ask, At what point could the influx of federal dollars compromise the measure of independence we seek? This concern will be a continuing question for my successor. My own three highest priorities for sustaining independence are to retain the ability to pay in full for Staff Members' compensation; to continue annual investments in new instrumentation; and to support postdoctoral fellows.

Contributions from trustees, friends, and private foundations are another vital source of funds. Prior to 1990, the institution had no sustained capacity for seeking external funds. The effort began in earnest with the arrival of Susanne Garvey in 1992. With a tiny staff but a lot of inventive strategic planning, she led us through our first capital campaign, which raised $40 million by its conclusion in December 1996. At the Department of Plant Biology, new laboratories were built and older ones refurbished. The Observatories campus metamorphosed from an unsightly warren of largely condemned buildings and trailers to a lovely campus with modern shops for instrument construction and a restored 1912 Myron Hunt building and Hale Library. Additions were made to the endowment, including the establishment of the Barbara McClintock postdoctoral fellowships. The campaign, together with a loan, allowed construction of the first Magellan telescope, now known as the Walter Baade telescope. Garvey then organized a successful drive for $6.5 million to restore our venerable administration building, outfit it with modern systems, and install laboratories and classrooms for the Carnegie Academy for Science Education (CASE). The fund-raising effort improved our previously obscure identity in the city. Capital Science, the free public lecture series now in its 13th year, has also enhanced Carnegie's visibility. More than 100 outstanding scientists, all with a gift for explaining their work to a general audience (some even emulating stand-up comics), have contributed to the goal that is embodied in our slogan "Science for the City." The lectures regularly attract an audience of between 350 and 400 people of all ages to the Root Auditorium. Our own efforts are complemented by the remarkable renewal of our neighborhood, which is again as it was early in the 20th century, a lively and even elegant urban place.

Although construction was just about under way for the co-location project when I arrived in 1988, the DTM and GL staffs were not certain that the outcome would be salutary. The goal of the project was to enhance scientific exchange and collaboration between the two departments, whose interests in Earth and planetary sciences increasingly overlapped. Scientists are always ready to accept new ideas about natural phenomena but tend to be surprisingly conservative and pessimistic when it comes to other kinds of change. The anticipation of new facilities, surely welcome in principle, was diminished by a fear of losing the individuality of

the two departments as well as the historic GL building on Upton Street. Happily, the concern that accompanied the complex move into the new facilities at Broad Branch Road has given way to collaborations and new research as my predecessor, James Ebert, predicted (see Director's Report by Charles Prewitt of GL in Year Book 1997-1998).

One department, Embryology, was left behind in the spate of facilities renewal during the 1990s. Aside from minor improvements and the imaginative redesign of existing spaces, the department still occupies an outmoded 40-year-old building on the Johns Hopkins University campus. Better late than never, change is coming. The current fund-raising campaign is, in part, to support construction of a new department home on the fine site generously offered by the university (Fig. 2). Construction should have begun by the time this Year Book is published. It was marvelously gratifying to learn that the trustees plan to name the new laboratory after me.

Fig. 2. This is a schematic of the new Maxine F. Singer Building for the Department of Embryology on the Johns Hopkins campus. (Courtesy Zimmer Gunsul Frasca Partnership.)

New Science

The proof of refreshing research is not in administration, facilities, instruments, funding, or the size of the scientific staff. It is in the new paths these elements forge for research. There have been new paths aplenty, and it has been a struggle to choose just a few to highlight.

A great deal of attention has been paid to the success of projects to sequence entire genomes, including the human genome. We are proud that Carnegie scientists were instrumental in the genome projects for *Drosophila* and *Arabidopsis* (Fig. 3). The DNA sequences are tremendous resources that will be used in biological research and medicine for decades, if not centuries, to come. Currently, the effort to elucidate the mechanisms that control gene activity is intense. An unanticipated discovery in 1997 by Andrew Fire and his colleagues at the Department of Embryology is at the center of much of this work (Fig. 4). They began a revolution when they observed that double-stranded RNAs, at exquisitely low concentrations, inhibit the activity of nematode genes bearing the same nucleotide sequence in their coding regions. The process is referred to as RNAi (for RNA interference). Now it is evident that the mechanism works in virtually all animals and plants and in isolated cells as well as whole organisms. The literature prior to the discovery had hints of some unusual control mechanisms, particularly in plants, but Fire's work opened the door to explaining these observations. His discovery initiated a whole new field of research for scientists worldwide. Because RNAi both advances fundamental knowledge in an unexpected way and is an exquisite new tool for pinpointing the action of a particular gene, its impact has been huge.

Many discoveries in contemporary biology unintentionally confirm the concept of evolution. The RNAi story, for example, tells us that this mechanism is ancient and was already present before evolution started on separate tracks for plants and animals. Similarly, work with diatoms by Arthur Grossman at Plant Biology (Fig. 5) has

Fig. 3. The model organisms *Drosophila* (above) and *Arabidopsis* (below) are used extensively in genetics research to determine the mechanisms that control gene activity.

implications for evolution, although finding such implications was neither his purpose nor was mentioned in his publication about the research. These diatoms normally require light for energy and growth; they are unable to take up sugar as a substitute for light. What Grossman and his colleagues did was to introduce a single human gene, which fosters the uptake of sugar, into the diatom cells. The transformed diatom grows well even in the dark if sugar is present in the surrounding water. This alga can now be grown commercially in standard fermenters rather than in outdoor sunlit pools, making them an efficient source for the production of important and hard-to-come-by chemicals. More fundamentally, these experiments demonstrate that the gain of a single gene can influence profoundly the ability of an ancient organism to thrive in a new ecological niche—in this case, in the dark rather than only on the surface of the ocean where light is available. The reverse might also be expected; the loss of a gene could force an organism to the uppermost layer of water. Since Darwin, biologists have argued about whether evolution occurs gradually through small changes or in leaps. The diatom story (and others) tells us that very small changes can themselves yield leaps.

When the Geophysical Laboratory was established in 1905, one of its goals was to investigate the effect of pressure on as wide a range of materials

Fig. 4. Andrew Fire (middle, in blue jacket) poses with members of his lab in 2001.

as possible to learn more about the nature of the deep Earth. Through an entire century, GL Staff Members pursued technology for reaching higher and higher pressures. Today, with the diamond-pressure cell, even the pressure at the center of the Earth is within the laboratory's toolbox. However, the capabilities of the cell depend on the ability to "see" what is happening to the material trapped between the tiny diamonds. Russell Hemley and David Ho-kwang Mao at GL have devised many new ways of seeing inside the cell, most recently techniques that depend on shining highly energetic X-rays through the diamonds. Such X-rays are not available at the corner scientific supply house. In the United States, they are generated only at the huge synchrotron rings built by the U.S. Department of Energy, where a whole complex laboratory must be constructed to exploit the potential of the tiny diamond cells. Several of us gathered at beamline 16 at the Advanced Photon Source (APS) at Argonne National Laboratory (Fig. 6) on July 26, 2002, to break a figurative bottle of champagne on the series of hutches and newly designed equipment that will allow GL scientists to maintain worldwide leadership in high-pressure research. The beamline is an outpost of GL with its own staff including postdocs, who are all efficiently supervised by an outstanding scientist/engineer, Daniel Häusermann. The implications of this research extend well beyond understanding our own planet. Jupiter, for example, is largely composed of hydrogen, one of the targets of the high-pressure research. Even more broadly, the work is important for understanding the chemistry of various materials at high pressure. What we once called "mineral physics" is increasingly "materials science."

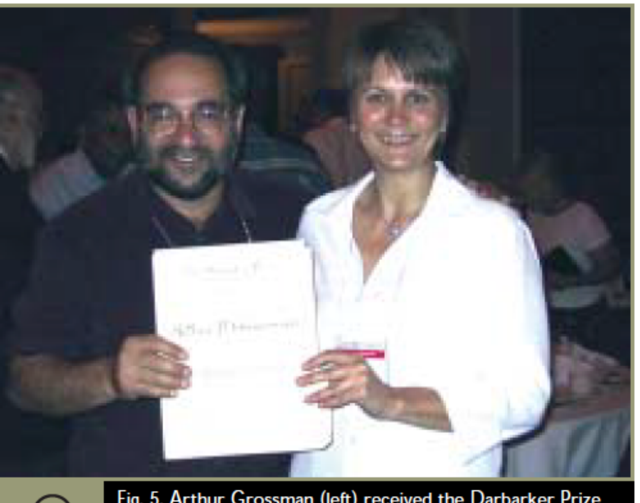


Fig. 5. Arthur Grossman (left) received the Darbarker Prize from the Botanical Society of America in August 2002.

On December 10, 2000, after a decade of planning and building, we broke another figurative bottle of champagne over the Magellan Project's Baade and Clay twin 6.5-meter telescopes high in the Andes. The bishop of La Serena sprinkled a minuscule amount of holy water on the telescopes while the astronomers and 300 guests held their breath. It is generally agreed that the innovative design and capabilities of the Magellan telescopes are a triumph for Stephen Shectman of the Observatories, who is their chief architect. There is also great admiration for project managers Peter de Jonge and Matt Johns, and for the dedicated people who brought the project to completion significantly under budget. Now, the focus is on designing and building instruments for the telescope. Alan Dressler and others are devoting themselves to the these essential undertakings. A little-appreciated aspect of the Magellan Project is the extraordinary sacrifice made by Observatories Staff Members who set aside potential research projects to contribute to the effort. Their agreement during these years to forgo access to large private telescopes so that most of their resources could be applied to Magellan was exemplary. Although this arrangement was made more tolerable to them by their intense involvement with the Hubble Space Telescope, few other institutions can boast such faculty commitment to a shared institutional vision. As these words are being written, both telescopes are functioning for scientific work.

When planning for Magellan began, the idea was to see farther and farther into the universe and thus back in time. Few imagined that the telescopes would also seek out planets around nearby stars in our own galaxy. Interest in planet formation began when George Wetherill's research, in a classic example of DTM history, evolved from the chemistry of meteorites into modeling the

Fig. 6. The Advanced Photon Source at Argonne National Laboratory is the location of Carnegie's High Pressure Collaborative Access Team, who perform world-renowned high-pressure research. (Courtesy Argonne National Laboratory.)

history of the solar system. Now DTM is an exciting center for planetary research. Geochemists, cosmochemists, theoreticians, and observational astronomers have all embraced the field, reaching within our own solar system and beyond to planets around other stars. Planetary research stimulates curiosity over the possible existence of life elsewhere in the universe and is of a piece with efforts to understand the conditions that are hospitable to the formation of life anywhere. Astrobiology, a field that did not exist 10 years ago, encompasses this range of activities and engages scientists at GL and DTM. Since we have learned that even on Earth living things can occupy unexpected niches such as the hydrothermal vents in the deep ocean, it is essential that we understand the chemistry of such extreme environments.

All these past accomplishments concern the future as well. They set the stage for new investigations and unpredictable outcomes. Carnegie's future also holds something entirely new—the Department of Global Ecology, established on July 1, 2002, in celebration of the institution's centennial (Fig. 7). To understand the changes wrought on Earth by natural phenomena and human activity, the traditional emphasis of ecology must be broadened to include vast ecosystems. The tools are now at hand for establishing patterns that link the physiology of individual organisms and small niches to large-scale phenomena in the ocean and the atmosphere and on land. These tools include spectral data from satellites, computer databases, mathematical and computer modeling, physiology, biochemistry, and molecular biology. Few enterprises could be more pertinent for the future than to learn how to maintain the conditions for life on our planet. Moreover, important conceptual ties exist between the program for global ecology and astrobiology at DTM and GL. Particularly intriguing are the differences between Earth as it was more than 4 billion years ago and the way it is now: life itself

Fig. 7. Global Ecology Staff Member Greg Asner and his son unveil the new sign for the campus the department shares with Plant Biology.

has brought change to our planet and its atmosphere. Analyzing these past changes can help illuminate the causes of the changes we see today.

New Contributions to Science Education

Postdoctoral and graduate students have long been common figures at the Carnegie departments, and the institution is seriously committed to its responsibility to train the next generation of scientists. Decades ago, we could count on the schools to inspire children to pursue serious scientific study. In recent years, however, we have increasingly recognized that there are widespread shortcomings in math and science education. Fewer and fewer young Americans arrive at college with a commitment to study science. Research institutions now have an obligation to assure a flow of younger students into science if we are to sustain our nation's technical and economic leadership in the future. CASE's science and mathematics programs are directed toward children and teachers in the Washington, D.C., public elementary schools and have been functioning for more than a decade. After a great deal of effort and frustration, we now have some confidence that we are accepted, even welcomed, by the school system. Evidence of progress is beginning to accumulate.

The departments too have initiated science education efforts. The Department of Embryology began years ago to provide scientific expertise to Baltimore high school teachers and students. Now its staff meets regularly with young women from inner-city high schools to stimulate an interest in science in a program called Serious about Science. This past summer, the Observatories engaged Pasadena high school students in an exciting, intense summer program in astronomy. At the Geophysical Laboratory, a senior fellow teaches chemistry weekly at a Washington, D.C., school. The Department of Plant Biology is making plans for a project in East Palo Alto. The two departments at Broad Branch Road have long had a successful summer science intern program for undergraduates and talented high school students. Staff Members Robert Hazen, Alan Dressler, and Alan Boss have also written fine books about their own fields directed to the general public. Carnegie is more engaged in science education than is readily apparent.

The Future

Carnegie's future will be shaped in part by external events. September 11, 2001, together with earlier and subsequent terrorist attacks at home and abroad, awakened us all to novel threats to global society and our nation. Science and scientists can make essential contributions to efforts to combat terrorism. In fact, Carnegie scientists and colleagues from other institutions have sought ways to participate in such efforts. They have been frustrated by our government's inability or unwillingness to organize relevant programs, marshal the scientific community in a coherent manner, or even respond productively to volunteers. The one exception is with respect to bioterrorism, where Anthony Fauci at the National Institutes of

Health has taken the tasks in hand. Fauci reminds me of Vannevar Bush in the days just before World War II. As Carnegie's president, Bush boldly assumed responsibility to counter the bureaucracy, secrecy, and rivalries within the military establishment that had insulated it from the most innovative scientific and technical ideas. He inspired Carnegie scientists and others to engage in wartime challenges.

Today, in addition to the military, the Department of Homeland Security and the independent national security and intelligence agencies acknowledge the importance of science. However, they tend to seek answers to questions of their own devising. As before, this behavior closes off access to external ideas, which restricts the advice the government receives. If government officials sought out people with different perspectives, who asked novel questions informed by the latest scientific knowledge, useful solutions to our new challenges might emerge more quickly. It is still early in our encounter with terrorism. In time, the government may come to realize the benefits it can gain by turning to more scientists for their wisdom and knowledge. If this happens, individuals at Carnegie will need to consider whether and how to become involved.

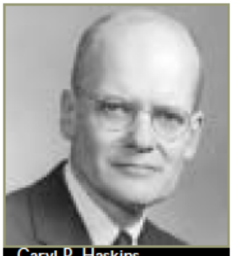
It has been my great fortune to preside over the Carnegie Institution during years of relative peace, freedom from fear, and healthy economic conditions, all of which fostered marvelous scientific advances. Surely I was not alone in sometimes imagining that such a world could go on forever. Yet already, we see that the next decade will bring a more demanding landscape for science. The changing economic scene has already had a significant effect on the availability of private funds for research. Our own endowment, which for two years has returned more to us than most endowments, will no longer support the substantial annual spending increase we enjoyed during the past few years. Compared with the Carnegie endowment, foundations that have been our friends have lost more and have been announcing or implying substantial cutbacks in their programs. Even before the cutbacks, many private foundations began to devote more and more of their resources to social programs, often those conceived by their own staffs. Corporate support of science has also waned except for research that can clearly enhance the corporations' aims. And, in very sharp contrast to its support of biomedical science, the federal government's investment in the physical sciences, including Earth science and ground-based astronomy, has significantly decreased. Although these developments will be a certain challenge for my successor and his Carnegie colleagues, the institution is in good health for coping with this changing climate.

Among the assets that assure Carnegie's future is the sound and thoughtful leadership of the gifted and dedicated department directors. They, above all, map the future of the institution through their respect and support for the scientists' vision. For me, as president, the greatest pleasure has been learning from the directors and scientists about the refreshing ideas and discoveries in their fields and in their own research. In my years at Carnegie, they gave me a richer outlook on the natural world than I had previously had or imagined. By allowing me to be colleague and friend, they enriched my life and tenure. I thank each and every one.

—Maxine F. Singer
November 2002

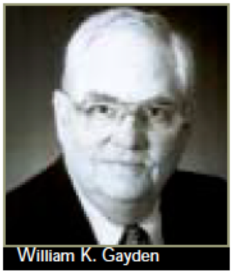
LOSSES

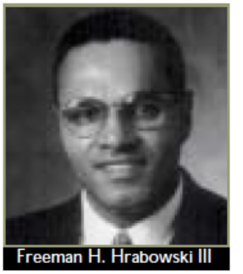
Former Carnegie president and trustee emeritus Caryl P. Haskins died on October 8, 2001, at the age of 93. He was president of the institution from 1956 to 1971. Haskins graduated from Yale in 1930 and received a Ph.D. in physiology from Harvard in 1935. He founded Haskins Laboratories and remained close to the Carnegie after his departure.

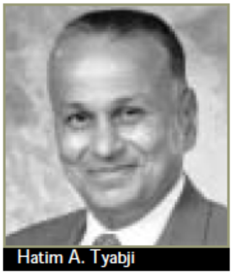

Caryl P. Haskins

GAINS

In May the Carnegie board of trustees welcomed three new trustees: William K. Gayden, chairman and CEO of Merit Energy Company; Freeman H. Hrabowski III, president of the University of Maryland, Baltimore County (UMBC); and Hatim A. Tyabji, formerly chairman and CEO of Saraide, Inc.


William K. Gayden


Freeman H. Hrabowski III


Hatim A. Tyabji

Plant Biology welcomed Staff Member Kathy Barton and adjunct Staff Members Matthew Evans and Devaki Bhaya. Barton explores the mechanisms by which plant meristems control plant architecture. Evans is characterizing the genes needed for the development of gametophytic tissues in maize. Using the microorganism cyanobacterium, Bhaya investigates how this photosynthetic organism uses light effectively by moving toward it or away from it.

Gregory Asner became the first new Staff Member for the new Department of Global Ecology. Asner uses remote sensing in his bottom-up approach to understanding the world's ecosystems.

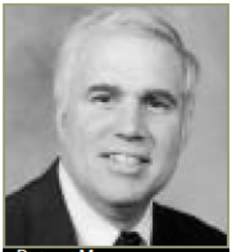
Staff Member Sara Seager joined the Department of Terrestrial Magnetism (DTM) this past summer. Seager's fields of study are cosmology and extrasolar planets.

TRANSITIONS

Carnegie trustee Kazuo Inamori was named trustee emeritus at the May 2002 board meeting.

Astronomer John Graham of DTM became Staff Member Emeritus.

HONORS



Richard Meserve

Trustee Richard Meserve was elected to the American Philosophical Society in April 2002.

Maxine Singer received the first-ever Rosalind Franklin Award from the National Cancer Institute in January 2002. She was also recognized for her outstanding accomplishments as a scientist and her dedication to the community with the Weizmann Award from the Weizmann Institute.

Wesley Huntress, director of the Geophysical Lab (GL), was selected by the American Institute of Aeronautics and Astronautics to receive the Dryden Lectureship in Research.

This past summer Christopher Somerville, director of the Department of Plant Biology, was elected to the Academia Europaea.

Vera Rubin

Senior Fellow Vera Rubin at DTM joined the ranks of such notable figures as Thomas Edison, Marie Curie, and Vannevar Bush by earning the John Scott Medal for her "major role in changing the way we think about our universe."

DTM Staff Member Alan Boss was named a fellow of the Meteoritical Society at the society's Los Angeles meeting.

Paul Butler, with Geoff Marcy (UC-Berkeley) and Steve Vogt (UC-Santa Cruz), received the 2002 Beatrice M. Tinsley Award from the American Astronomical Society for his "pioneering work in characterizing planetary systems orbiting distant stars."

Alan Linde, Staff Member at DTM, was elected a fellow of the American Geophysical Union (AGU) at the spring AGU meeting in May.

Douglas Rumble of GL was elected vice president of the Mineralogical Society of America for 2002 and president for 2003. He was also elected a fellow of the Geological Society of America.

Ronald Cohen of GL was elected a fellow of the American Geophysical Union.

DTM's Alycia Weinberger was awarded the 2000 Vainu Bappu Gold Medal of the Astronomical Society of India, which is presented every two years.

Toward Tomorrow's Discoveries

The Carnegie Institution received gifts and grants from the following corporations, foundations, individuals, government agencies, and other sources during the period July 1, 2001, to June 30, 2002.

CORPORATIONS AND FOUNDATIONS

$100,000 to $1 Million

The Hearst Foundation, Inc.
Howard Hughes Medical Institute
The G. Harold and Leila Y. Mathers Charitable Foundation
Ambrose Monell Foundation
The David and Lucile Packard Foundation
Sidney J. Weinberg, Jr. Foundation

$10,000 to $99,999

Abbott Laboratories Fund
Ahmanson Foundation
Carnegie Institution of Canada/Institution Carnegie du Canada
Fondation de France
Golden Family Foundation
Philip L. Graham Fund
David Greenewalt Charitable Trust
Richard W. Higgins Foundation
IBM Corporation
Suzanne and David Johnson Foundation
Pearl Family Fund
The Deborah Rose Foundation
Verizon
Wallace Genetic Foundation, Inc.
The Weathertop Foundation
The Helen Hay Whitney Foundation

$1,000 to $9,999

The Bristol-Myers Squibb Foundation, Inc.
Cavalieri-Look Fund
The Charlotte and Gary Ernst Fund
Paul and Annetta Himmelfarb Foundation
The Leonsis Foundation
Pfizer Foundation Matching Gifts Program
Hattie M. Strong Foundation, Inc.

Under $1,000

Borders, Inc.
Carnegie Corporation of New York
Science and Technology International Inc.
Whole Foods Market
Wim Two Inc.

INDIVIDUALS

$100,000 to $1 Million

D. Euan Baird
Michael E. Gellert
William R. Hearst III
Richard E. Heckert
Gerald D. Laubach
Burton J. and Deedee McMurtry
William J. Rutter
Tom and Mary Urban
Ladislaus von Hoffmann

$10,000 to $99,999

Philip H. Abelson
Bruce Alberts
Bradley F. and Virginia W. Bennett
Tom Cori
John F. Crawford
The Estate of James and Alma Ebert
Jo Ann Eder
Julie Davies Forbush Trust
Robert and Alexandra Goelet
Robert and Margaret Hazen
Helen M. Hindle
Jaylee and Gilbert Mead
Evelyn Stefansson Nef
Allan Sandage
Sara Lee Schupf
Christopher T. S. Stone
David and Susan Swensen
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Dogwood and Green Acres Road Association

THE DIRECTOR'S REPORT

FIRST LIGHT SATURDAY SCIENCE SCHOOL, 1989–PRESENT
CARNEGIE ACADEMY FOR SCIENCE EDUCATION (CASE), 1993-PRESENT

The Carnegie Institution began its work to improve science education in the public schools of the nation's capital as the 20th century was ending. Since the beginning, our focus has been on the children and what happens in the classroom. From our decade of experience, we have learned that in schools where administrators and teachers place their highest priority on quality instruction, the students thrive academically. It has also become clear to us that the successful pupils in these schools are expected to achieve and are given the resources to do so. Although the academic institutions that foster this environment are located in both high- and low-income areas, most of the city's schools do not operate this way.

During the early years, the Carnegie Academy for Science Education (CASE) worked at individual schools independently of the D.C. Public Schools' (DCPS) central administration. In 2000, CASE entered into a partnership, called DC ACTS, with the DCPS and the American Association for the Advancement of Science under a cooperative agreement funded by the National Science Foundation. Through the partnership, DC ACTS has crafted quality standards for science and mathematics, expanded the institutes and courses offered to teachers by CASE to include technology instruction, and spurred the development of science and mathematics programs at several DC ACTS elementary schools. As a result, DCPS administrators, principals, and teachers have come to recognize the high quality of professional development that CASE provides (Fig. 1 and Fig. 2).

In 2002, students in First Light, the Saturday science school, became the beneficiaries of a growing legion of CASE partnerships. Greg Taylor, the First Light coordinator and lead teacher, received a master teacher certificate and a $5,000 grant from the Intel and Microsoft corporations for participating in the Intel® Teach to the Future program. This program is a worldwide effort to help teachers integrate technology into their instruction and enhance student learning. Participating teachers receive extensive training and resources to promote effective technology use in the classroom. The grant was used to purchase computer equipment for First Light. Students

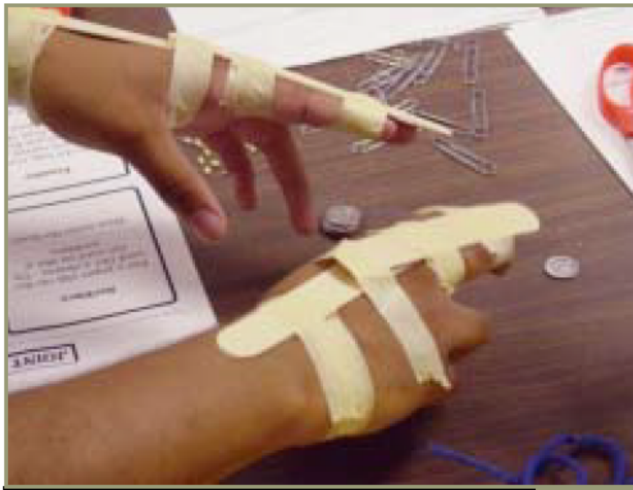


Fig. 1. Hands-on science takes on a new meaning in this exercise in which the joints of the hand are immobilized so students can understand how important they are to everyday tasks. (Courtesy Gregory Taylor.)

Left: First Light students learn about chemical reactions. (Courtesy Gregory Taylor.)

Fig. 2. CASE's associate director, Dr. Julie Edmonds (flowered dress), evaluates one CASE teacher's summer project involving plant collection. (Courtesy Gregory Taylor.)

learned how to use the equipment by documenting their experiments and field trips using digital cameras, creating multimedia presentations, and starting a First Light Web page.

The DC ACTS partnership with Intel and Microsoft also helped CASE secure other funding. The Philip L. Graham Fund awarded the program a $40,000 grant to purchase more computer equipment, and Verizon gave a $20,000 grant to develop the CASE/First Light Web site. The funds have been put to good use. The standards-based thematic units, which were created by CASE fellows, have been posted on the Web page for easy access. With its newly renovated 20-station computer lab, CASE also has been able to launch a Summer Technology Institute for DC ACTS teachers. To date, more than 100 D.C. public-school teachers have received CASE computer training.

In another effort, the Living Classrooms Foundation, in partnership with the Chesapeake Bay Foundation, the Anacostia Watershed Society, and the Interstate Commission for the Potomac River Basin, sponsored the "Schools in Schools: Shad and Herring Raise and Release Project" at First Light and three DC ACTS elementary schools. Students in more than 20 classrooms in the metropolitan area received fully equipped hatch tanks and shad eggs in the spring of 2002. For one week, the students maintained their hatch tank's water temperature and chemical composition and monitored the mortality rate of

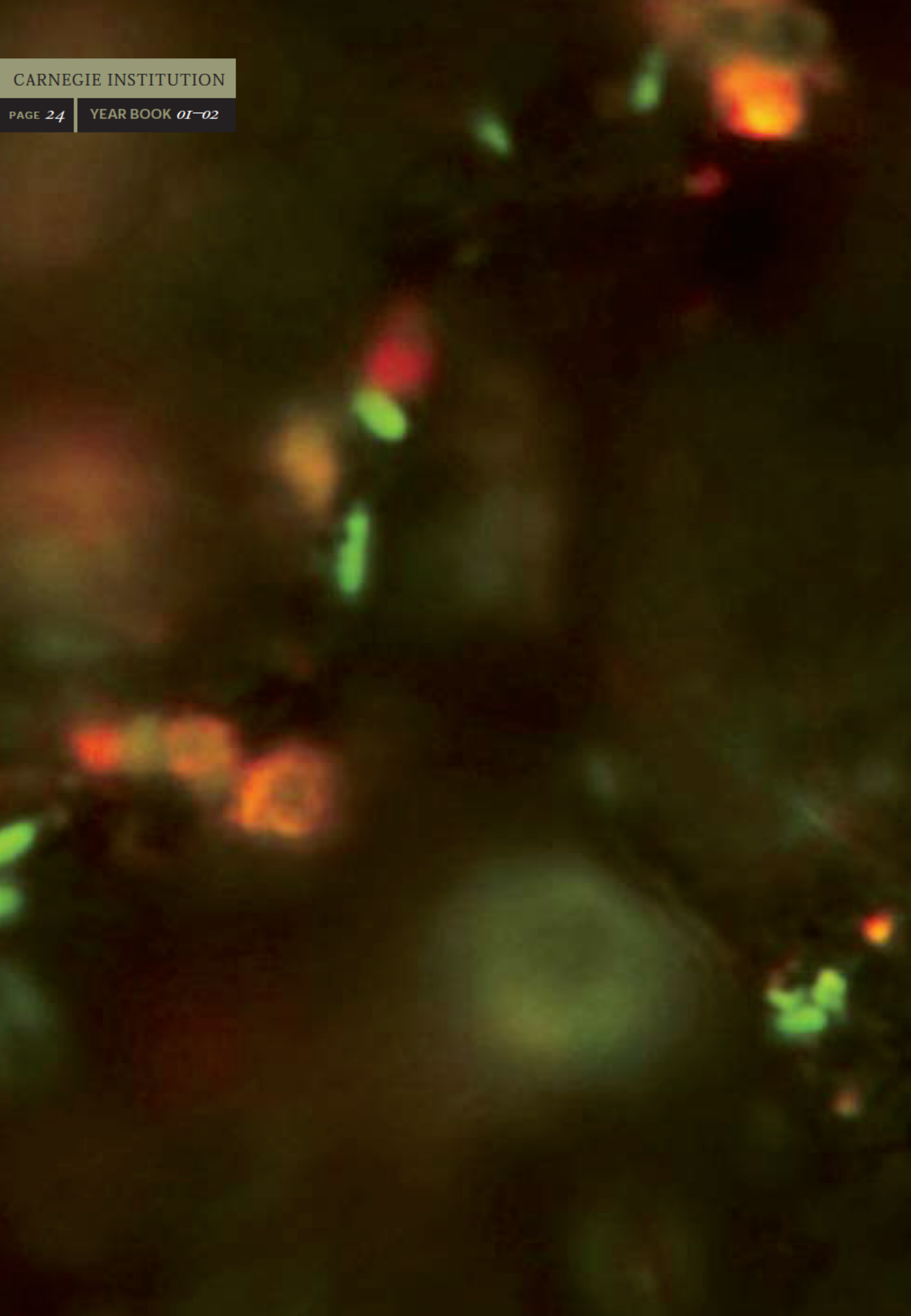
their eggs to ensure maximum hatching. Later in the spring, the students released over 3,500 surviving fry into the Potomac River to culminate the project (Fig.3).

As we look ahead, the future of First Light is brighter than ever. Students will build upon the experiences of 2001-2002 as they embark on new and exciting adventures. Plans are under way to expand the Saturday school to include middle and high school students and develop partnerships with scientific research organizations so that students can become involved in real-world scientific investigations.

We hope that through these partnerships, First Light and CASE can continue to bring science to the city's children and teachers well into the 21st century.

—Inés Lucía Cifuentes

Fig. 3. First Light students prepare to release herring and shad hatchlings in the Anacostia River. The project was part of a partnership with the Living Classrooms Foundation, the Chesapeake Bay Foundation, the Anacostia Watershed Society, and the Interstate Commission for the Potomac River Basin. (Courtesy Gregory Taylor.)



THE DIRECTOR'S REPORT

The Geophysical Laboratory (GL) continues its world-class research into the basic physics and chemistry of the Earth and other planets, including the fundamental properties of materials at the temperatures and pressures equivalent to those in planetary interiors. To understand the formation of the Earth and the evolution of its surface biology, the lab is also strengthening its work on extraterrestrial materials and the study of prebiotic chemical processes that led to the first biology.

Fundamental Properties of Materials

Clathrate hydrates

Clathrate hydrates are ices that form molecular "cages" of frozen water, which can host foreign molecules inside. Studying the H_2-H_2O system, GL scientists made a clathrate at moderate pressures in which water cages were filled by different clusters of two and four hydrogen molecules (Fig. 1). They found novel hydrogen-host interactions using synchrotron X-ray diffraction, neutron diffraction, infrared (IR), and Raman spectroscopy. H_2 and H_2O are the most abundant gas and ice molecules in the universe. The large stability range of this clathrate suggests that it is pervasive and possibly important to the evolution of icy bodies in interstellar space and in planetary systems.

Superconductivity in boron

Scientists at the laboratory and the Center for High Pressure Research continue to subject materials to ever higher pressures, breaking records and discovering new materials and fundamental properties along the way. Mikhail Eremets, Viktor Struzhkin, Ho-kwang Mao, and Russell Hemley subjected the light element boron to pressures up to 250 gigapascals (GPa) (2.5 million times the atmospheric pressure at sea level) and tested for electrical conductivity. The experiment marks the highest pressure under which electrical conductivity and superconductivity have been measured in dense matter.

Earth and Planetary Interiors

Planetary cores: iron at high pressure and radioactive heat

Magnetism and elasticity in iron

Staff Member Ronald Cohen and Carnegie Fellow Gerd Steinle-Neumann continued their efforts to understand elasticity and magnetism in high-pressure iron. Iron is not magnetic at the pressures and temperatures of the Earth's core; but at lower pressures and temperatures, magnetism strongly influences the metal's properties. To better understand experimental data on the element, it is

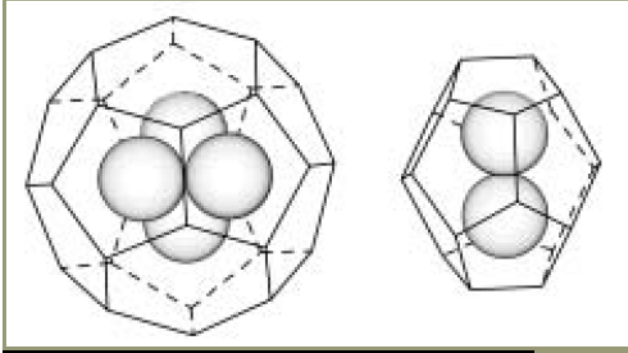


Fig. 1. Clathrate (cage) molecular structures in ice are shown with water molecules located at the corners of the polyhedra. This structure forms an internal cage that can hold two hydrogen atoms (right) or as many as four hydrogen atoms (left). (Reprinted with permission from *Science*, 297, 2247. Copyright 2002, American Association for the Advancement of Science.)

Left: The green glowing spots on the surface of this meteorite are *Staphylococcus* cells. See Figure 3 for details.

crucial to understand the effects of magnetism on it. The researchers noticed an interesting splitting in Raman data on iron. They have now shown that the splitting and its pressure dependence indicate that iron has antiferromagnetic correlations at pressures below about 60 GPa. This result has important implications for extrapolating lower-pressure data to high pressures and for understanding the behavior of iron in Earth's interior.

Radioactive heat sources in planetary cores

Theory suggests that ^{40}K may be a radioactive heat source in the Earth's core. If true, this phenomenon would have major implications for the thermal evolution of the Earth. It would affect global processes and events such as convection in the outer core, the generation of the geomagnetic field, the heat flux at the core-mantle boundary, the time the inner core formed, plume dynamics, and possibly convection in the lower mantle. New experimental data, obtained by Visiting Investigator Rama Murthy, postdoctoral fellow Wim van Westrenen, and Staff Member Yingwei Fei, show that potassium could enter sulfur-bearing metallic cores of planets and serve as a heat source. The heat production due to ^{40}K in the Earth's core is 4 to 9 TW (TW = 10^{12} watts), a substantial fraction of the present core-mantle boundary heat flux. The existence of a core dynamo and the geomagnetic field for the past ~4 billion years is possible with this additional heat. ^{40}K heat production in the core of Mars, 0.1 to 0.4 TW, could have aided a dynamo driven by thermal convection early in its history.

Planetary mantles: between core and crust

Creep

Diffusion is the rate-limiting step in many kinetic processes in planetary interiors, including solid-state creep. The rates of these processes can be estimated if diffusion coefficients at the appropriate conditions are known. A central problem in estimating diffusion rates at the conditions of Earth's lower mantle (670 to 2,900 km) is the effect of pressure. Postdoctoral fellow James Van Orman and Staff Member Yingwei Fei have performed the first high-pressure measurements of cation and oxygen diffusion in periclase (MgO), an important component of Earth's lower mantle, at pressures up to 25 GPa. The study extends diffusion data over a larger range of pressure than has been determined for any other silicate or oxide material, thus reducing uncertainties in high-pressure extrapolations. The results for pure MgO agree with first-principles calculations.

Where's the hydrogen?

Coesite, a high-pressure SiO_2 polymorph, is stable at pressures higher than 2.7 to 3.0 GPa (about 100 km depth). Its occurrence in metamorphic rocks indicates that the host rocks were subjected to pressures equivalent to depths of at least 80 to 100 km. Hydrogen has not yet been detected in natural coesite samples from ultra-high-pressure metamorphic rocks. To interpret observations of natural coesite, researchers need to determine hydrogen solubility as a function of pressure, temperature, and chemical impurity. Research associate Monika Koch-Müller and Staff Member Yingwei Fei have investigated the incorporation of hydrogen into the coesite structure over a wide pressure and temperature range. They found that hydrogen can only be incorporated into the coesite structure of synthetic samples at pressures greater than 5.0 GPa and temperatures of 1373 K. The absence of hydrogen in coesite found in the metamorphic rocks may therefore indicate that they have not experienced pressures greater than 5.0 GPa. Diamond, on the other hand, was formed at pressures of at least 5.0 GPa. The researchers have found the first natural OH-bearing coesite inclusion in diamond, and the shift of the OH bands of coesite and omphacite to lower energies indicates that the minerals are still under confining pressure of 5.5 GPa.

Meteorites

Exploring organic chemistry in meteorites

The organic material in primitive chondritic meteorites has attracted considerable attention

because it retains a record of synthesis in the interstellar medium (ISM) and possibly in the solar nebula, and because it may have been an important component of the prebiotic organic material on the early Earth. Carbonaceous chondritic meteorites contain up to several percent of their mass in organic carbon, and of this 70% to 90% is composed of an insoluble, chemically complex macromolecular solid. Because of its insoluble nature, the macromolecular phase has resisted detailed characterization for decades.

Over the past year George Cody, collaborating with Conel Alexander and Fouad Tera of the Department of Terrestrial Magnetism, has been applying solid-state nuclear magnetic resonance (NMR) spectroscopy of protons, ^{15}N, and ^{13}C nuclei to this meteoritic organic residue, making a self-consistent chemical analysis of three important carbonaceous chondrites: Orgueil, Murchison, and Tagish Lake. The data reveal macromolecular organic material composed of a wide range of organic (aromatic and aliphatic) functional groups, including many that contain oxygen (e.g., organic acids, ketones, alcohols, and ethers). Each meteorite exhibits enormously complex organic chemistry, and across the suite of them there is an enormous difference in the relative abundances of each functional group (Fig. 2). This variation may reflect different processing histories in the early solar nebula.

Terrestrial organic matter in meteorites

New Staff Member Andrew Steele is looking at the extent of contamination of meteorites with terrestrial microbes and at what effects their growth, death, and metabolism have on the organic inventory. Steele applies well-known microbiological and biotechnology approaches, such as fluorescence microscopy, ATP luminometry, enzyme assays, polymerase chain reaction (PCR) and DNA/protein microarray screening to detect this contamination. The goal is to see if these techniques can detect life in extraterrestrial materials and to develop techniques for spacecraft flight instruments intended for places such as Mars. Steele also applies spectroscopic techniques, such as near-field Raman and IR spectroscopy/microscopy, chemical force microscopy, and time-of-flight secondary ion mass spectrometry (TOF-SIMS), to determine the character of meteorite organics as microbial contamination levels increase. Figure 3 shows what is probably a fungal spore on the surface of the Murchison meteorite. Figure 3 (right) is an image of the meteorite surface showing a number of green glowing *Staphylococcus* cells, demonstrating that fluorescence microscopy works for the detection of microbial contaminants.

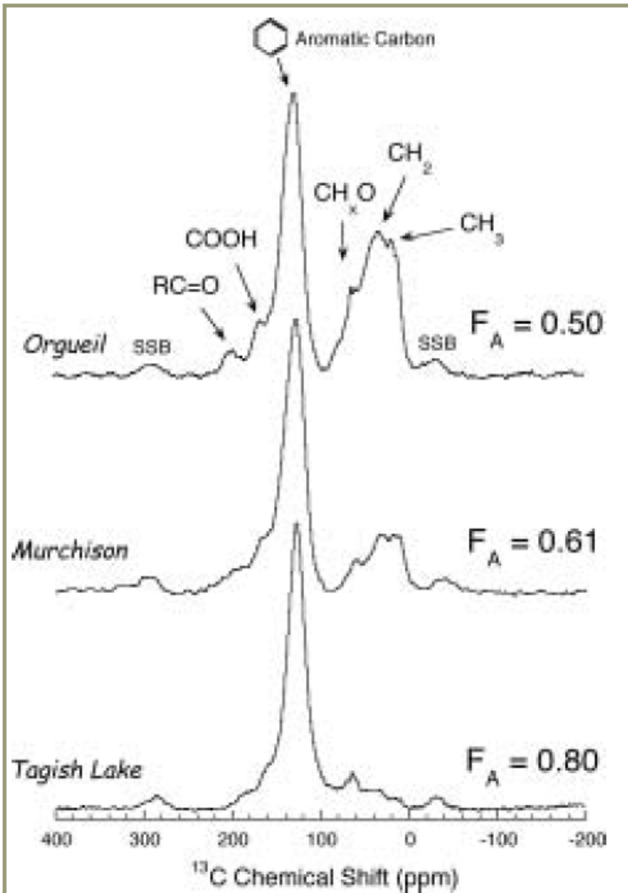


Fig. 2. Large differences in carbon chemistry are revealed by this solid-state ^{13}C NMR spectra of organic concentrates obtained from the Orgueil, Murchison, and Tagish Lake meteorites. Spectral regions that correspond to the presence of discrete functional groups—methyl (CH3), aromatic carbon, and carboxylic acid (COOH)—are noted.

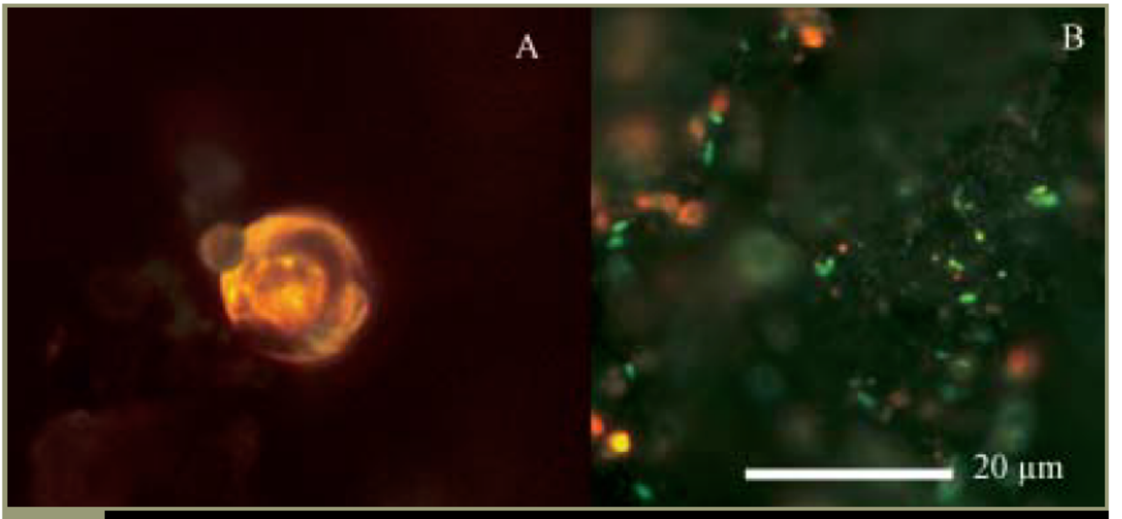


Fig. 3. The left image shows a fungal spore on the surface of the Murchison meteorite before contamination with bacteria. The right image is of the meteorite surface with a number of green glowing *Staphylococcus* cells.

Life on Earth

Looking for life's origins

Searching for ancient life on Earth

Steele, in collaborative work led by Martin Brasier of the School of Earth Sciences at Oxford University, reexamined purported cyanobacterial fossils in 3.5- to 3.8-billion-year-old chert samples from the Warrawoona area of Australia, using optical and electron microscopy, carbon isotope analysis, elemental mapping, and Raman spectroscopy combined with extensive mapping of the area. The alleged fossils are branched and inconsistent with a cyanobacterial origin. They are probably organic material formed around crystal faces, making them an artifact of the initial microscopic investigation. This result is more consistent than previous results have been with other evidence that photosynthetic organisms such as cyanobacteria did not arise on Earth until about 2 billion years ago.

Searching for ancient prebiochemical processes

Bob Hazen, Hatten Yoder, and Jay Brandes (University of Texas, Austin) have studied catalytic effects of natural sulfides and oxides in the reduction of aqueous nitrate and nitrite solutions to determine which reactants may have contributed to the prebiotic synthesis of amino acids and other biomolecules. Transition metal sulfides (Fe, Co, Ni, Cu, Zn, Sn, W, Pb) rapidly convert nitrogen oxides to ammonia, with up to 90% conversion in 90 minutes. The conversion efficiency is generally lower for nitrite, which is less stable than nitrate under these conditions. Oxide minerals (Fe, Ni, Cu, Mn) also reduce nitrate and nitrite to ammonia, albeit with lesser yields than the sulfides. They found that ammonium in aqueous solution was stable at 300°C and 50 MPa in the presence of the sulfides and oxides, with no significant loss in 24 hours. It appears that ammonia is not rapidly destroyed in hydrothermal systems, suggesting that deep-ocean hydrothermal systems might have provided a significant source of ammonia for the Archean Earth, and consequently a source for production of amino acids and other nitrogen-containing biomolecules.

Searching for ancient biochemical processes

George Cody, Kevin Boyce, and Andy Knoll (Harvard University) have been using scanning transmission X-ray microscopy (STXM) at carbon's 1s absorption edge at Brookhaven National Laboratory to analyze the carbon chemistry of

well-preserved 400-million-year-old plants. They investigated some of the most primitive vascular plants, *Rhynia* and *Asteroxylon*, and used STXM to determine whether different regions of the vascular cell membrane ever contained the biomolecule lignin. Lignin is the structural biopolymer in plants that strengthens the cell wall, protects against microbial attack, and enhances water-storage capacity. The investigators want to know when vascular plants colonized the continents; the emergence of lignin biosynthesis may have facilitated this event.

Using the transmission X-ray microscope, the researchers were able to show that individual tracheid walls in both Eocene and Early Devonian fossils exhibit spatially distinct chemical zoning, which is inherited from original wall biopolymers and cell-wall microstructure (Fig. 4). This zonation is consistent with lignin deposition having occurred in the primitive Devonian plants, possibly following biochemical and developmental pathways similar to those of living tracheophytes.

Life under pressure

Examination of microbial physiology at high pressure

Staff Associate James Scott and Astrobiology Associate Anurag Sharma have found that the pressure-sensitive microorganism *Shewanella oneidensis* MR-1, a gram-negative bacterium capable of using metals as terminal oxidants, and the gram-negative bacterium *Escherichia coli* are both capable of surviving pressures greater than 1.5 GPa (Fig. 5). These organisms metabolize formic acid at these pressures and survive within solid ice VI by forming organic-rich inclusions. These are the first experiments proving that microorganisms are capable of existing at extreme pressures equivalent to those 50 km below the Earth's surface and in the subsurface ocean of Europa, one of Jupiter's large satellites. The results imply that pressure may not be a significant impediment to life in the deep waters of Jupiter's moons, under the Martian polar caps, or in the subduction zones on Earth.

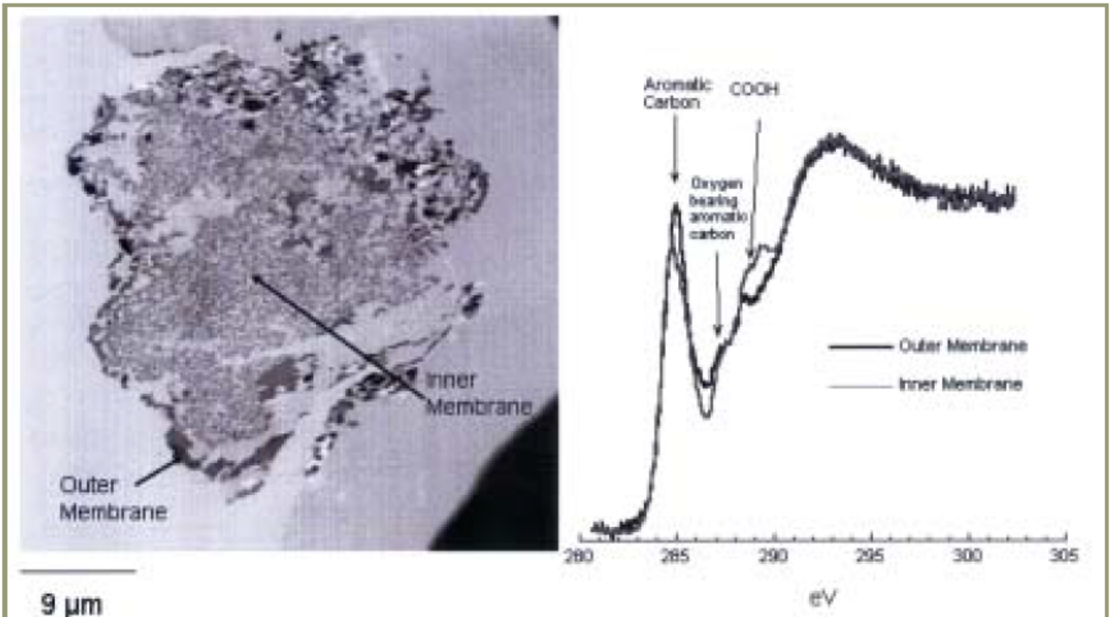


Fig. 4. Left: This high-resolution soft X-ray image of preserved remains of an ancient (~400 Ma) primitive plant (*Asteroxylon*) from the Rhynie Chert shows both the nearly intact outer cell membrane and the partly dispersed inner membrane of this ancient vascular plant. Carbon (1s) X-ray absorption near edge spectra (XANES) is indicated on the outer and inner regions of the cell membrane, revealing differences in carbon chemistry (right).

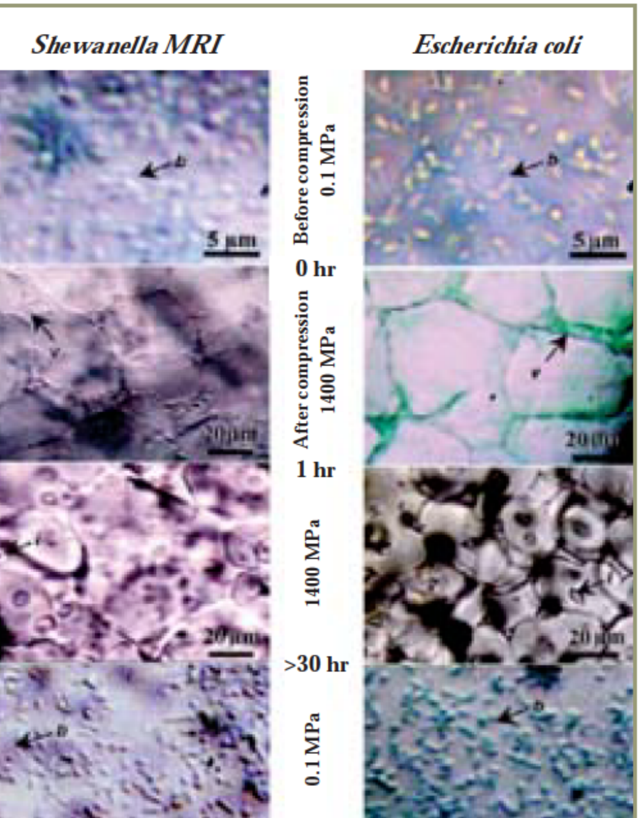


Fig. 5. Microbial activity and viability is apparent at 1.4 GPa in ice VI. Upon ice nucleation (0 hours), organic fluid veins (v) filled with bacteria appear (*Shewanella* MR-1 is on the left; *E. coli* stained with methylene blue is on the right). After one hour, textural changes in the ice occur, defined by the formation of organic-rich inclusions (*i*) containing motile bacteria. Viable (methylene blue in solution remains colorless, indicating respiration) and countable bacteria (*b*) were observed upon subsequent lowering of pressure. (Reprinted with permission from *Science, 295*, 1516. Copyright 2002, American Association for the Advancement of Science.)

In the Field

More recent fossils in Australia

Marilyn Fogel, postdoctoral researcher Matthew Wooller, and collaborators at the Australian National University (ANU) have examined dunes in Central Australia dating back 200,000 years to find buried remains of plant tissues, which contain a record of the vegetation, environment, and climate during the Pleistocene. Nigel Spooner of the ANU used optically stimulated luminescence (OSL) dating to determine the ages of the sand. The organic matter was measured at GL for the carbon isotopic record. The data showed that the vegetation's composition began to shift during the Last Glacial Maximum (22,000 to 20,000 years ago) and continues to the present. Plants associated with temperate climates with ample water were detected deep in the core samples, while plants that thrived under warmer, drier conditions were found in the more recent sands.

The isotopic and climatic record from the dunes (Fig. 6) is coupled with studies on fossilized eggshells from the extant emu and an extinct large, flightless bird called *Genyornis*. Using amino acid racemization dating and ^{14}C analysis of a single 1-cm-square fragment of eggshell, the group determined the specimen's exact age. The vegetation and climate of the area was then inferred from the bird's diet, which was evident from the eggshell. Based on the large numbers of eggshells found in very specific locations near lakes and embayments, the hypothesis is being tested that *Genyornis* was a colonial nesting bird that ate aquatic foods. If the birds returned to the same place time and again, they could have been easy prey for Aboriginal people. Results from previous collections confirm that eggshells of the emu, which nests anywhere in the arid interior, are found in more locations but in lower abundance. The team found that N and C isotopic compositions of the eggshells of the two species as a function of time are quite different, indicating a different nesting behavior and ecology. One survived the arrival of humans, the other did not.

Right next door on the Eastern Shore

The biogeochemical cycles on the Eastern Shore of the Chesapeake Bay are heavily affected by nutrients introduced into the environment from chicken farms. Birds synthesize uric acid as their primary vehicle for nitrogen excretion. Marilyn Fogel and collaborators found that uric acid in chicken manure is converted by bacteria within a few days to common nitrogen-containing compounds such as ammonium and nitrate, and that these compounds are readily used by plants and plankton in nearby streams. Uric acid, however,

Fig. 6. Marilyn Fogel is pictured on a dune in Central Australia with colleagues Gifford Miller (University of Colorado) and John Magee (Australian National University). Thousands of fragments of *Genyornis* eggshell were found at a site in the region, which they called Geny Heaven.

is detected in watersheds only in the cold winter months, when microbial activity is low. During that time, almost every stream and drainage ditch near a chicken farm is polluted with it.

Fogel tracked the levels of nitrogen-containing nutrients in waters, crops, and vegetation for over a year in several farms and streams adjacent to the Nanticoke River watershed. Some farmers were more successful than others in keeping the nitrogen from reaching streams because they planted enough corn and soybeans to incorporate most of the nutrients. Using stable nitrogen isotopes as tracers, she tracked chicken-waste nitrogen in the tissues of riparian plants, stream invertebrates, and aquatic microbes.

Fogel then conducted a series of laboratory experiments to determine uric acid breakdown by natural populations of microbes. She also started

Fig. 7. This is the Skaergaard excursion group with some of the layered intrusion rocks visible in the background in a central mountain called Wager Peak. The zone of Pd-Au enrichment is associated with the lowest of three prominent layering units discernible in the cliff face. It is inclined to the right and eventually drops below sea level in that direction, where it has been found to extend through almost half of the intrusion's area.

Fig. 8. Members of the Geophysical Laboratory staff shown on October 31, 2002. First row (from left):N. Boctor, B. Minarik, B. Brown. S. Clarke, M. Frank, R. Dingus, C. Prewitt, W. Huntress, I. Li, R. Torres, M. Bacote, A. Mao, D. Mao, and G. Cody. Second row: H. Scott, M. Sepliarsky, V. Struzhkin, I. Maule, Y. Yoshimura, H. Watson, H. Hellwig, S. Ono, P. Meeder, S. Schmidt. P. Wang, R. Hemley, B. Hazen, G. Bors, and A. Sharma. Third row: J. Scott, I. Toporski, A. Steele, C. Yan, Z. Wu, I. Boyd, H. Yoder, D. Rumble, N. Irvine, M. Wolf, M. Furlanetto, R. Cohen, S. Lee, and Y. Song. Fourth row: P. Dera, Y. Ding, C. Hadidiacos, B. Collins, G. Gudfinnsson, I. Straub, G. Steinle-Neumann, B. Mysen, N. Platts, S. Coley, and R. Scalco. Not pictured: A. Colman, P. Esparza, Y. Fei, M. Fogel, I. Frantz, D. George, S. Gramsch, S. Hardy, S. Lapel, B. Key, I. Lin, K. Mibe, D. Presnall, P. Roa, G. Sághi-Szabó, I. Shu, S. Stewart, and I. Xu.

experiments with ^{15}N-enriched uric acid in an unpolluted wetland, measuring the flow of uric acid N into plants and insects. Because uric acid is biologically unstable and highly reactive, these simple experiments were necessary to establish firm links in the biogeochemical cycle. Extrapolating from the laboratory to controlled experiments at specific field sites, Fogel and her coworkers investigated fish and higher organisms such as shrimp and blue crabs in three river systems: the Rhode River, a small watershed on the western shore with no poultry farming; the Nanticoke River, a large river-wetland system heavily affected by chicken farming in its upper reaches; and the Indian River, a small watershed with intensive chicken farming on its shores. The team collected hundreds of fish and analyzed them for their nitrogen and carbon stable-isotopic compositions. Using the isotopic tracers, they were able to determine that nitrogen from poultry wastes was making its way into the Chesapeake Bay fishery. With this background, scientists can now assess the Chesapeake watershed to determine whether its biogeochemical cycle is connected to poultry farming.

In Greenland

Neil Irvine continues to focus on the Skaergaard intrusion on the east coast of Greenland, situated at the mouth of a large inlet called Kangerdlugssuaq ("Big Fjord" in Inuit) just above the Arctic Circle (Fig. 7). The intrusion measures approximately 10 by 7 km and comprises three well-stratified lithostructural divisions. Irvine led a 13-day field excursion to Skaergaard in late August and early September 2001 with Jens C. O. Andersen of the University of Exeter, C. Kent Brooks of Copenhagen University, and 33 other participants. They operated from a Russian ship, the *Grigoriy Mikheev*. A major attraction was a 2-meter-thick stratiform zone of palladium and gold enrichment that spans most of the intrusion at approximately its stratigraphic midlevel. This zone is probably not rich enough to be mined, but it is similar to ore zones of palladium and platinum in several intrusions elsewhere, so understanding its nature and origin is scientifically and economically interesting.

—Wesley T. Huntress, Jr.

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June 30, 2001 – July 1, 2002

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continued on next page

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[1] From October 22, 2001
[2] From January 1, 2002
[3] Joint appointment with DTM
[4] From November 25, 2001
[5] Joint appointment with DTM
[6] To February 28, 2002
[7] From July 1, 2002
[8] From August 6, 2001
[9] To October 15, 2001
[10] From August 6, 2001
[11] From July 1, 2001
[12] From July 1, 2001
[13] From June 2, 2002
[14] From September 3, 2001
[15] To December 12, 2001
[16] To September 26, 2001
[17] From July 1, 2002
[18] From July 1, 2002
[19] To July 26, 2001
[20] From January 15, 2002
[21] To July 5, 2001
[22] From July 1, 2001
[23] To August 15, 2001
[24] From January 1, 2002 to April 30, 2002; from May 1, 2002
[25] From June 3, 2002
[26] To October 31, 2001
[27] From December 12, 2001
[28] To December 31, 2001
[29] From August 20, 2001
[30] From August 13, 2001
[31] From November 1, 2001
[32] From July 1, 2002
[33] From November 1, 2001
[34] From October 22, 2001
[35] To March 31, 2002
[36] From May 1, 2002
[37] From June 3, 2002
[38] From July 1, 2002
[39] To April 30, 2002
[40] Joint appointment with DTM
[41] From April 18, 2001; joint appointment with DTM
[42] Joint appointment with DTM
[43] Joint appointment with DTM
[44] Joint appointment with DTM
[45] Joint appointment with DTM; retired June 30, 2002
[46] Joint appointment with DTM
[47] Joint appointment with DTM
[48] Joint appointment with DTM

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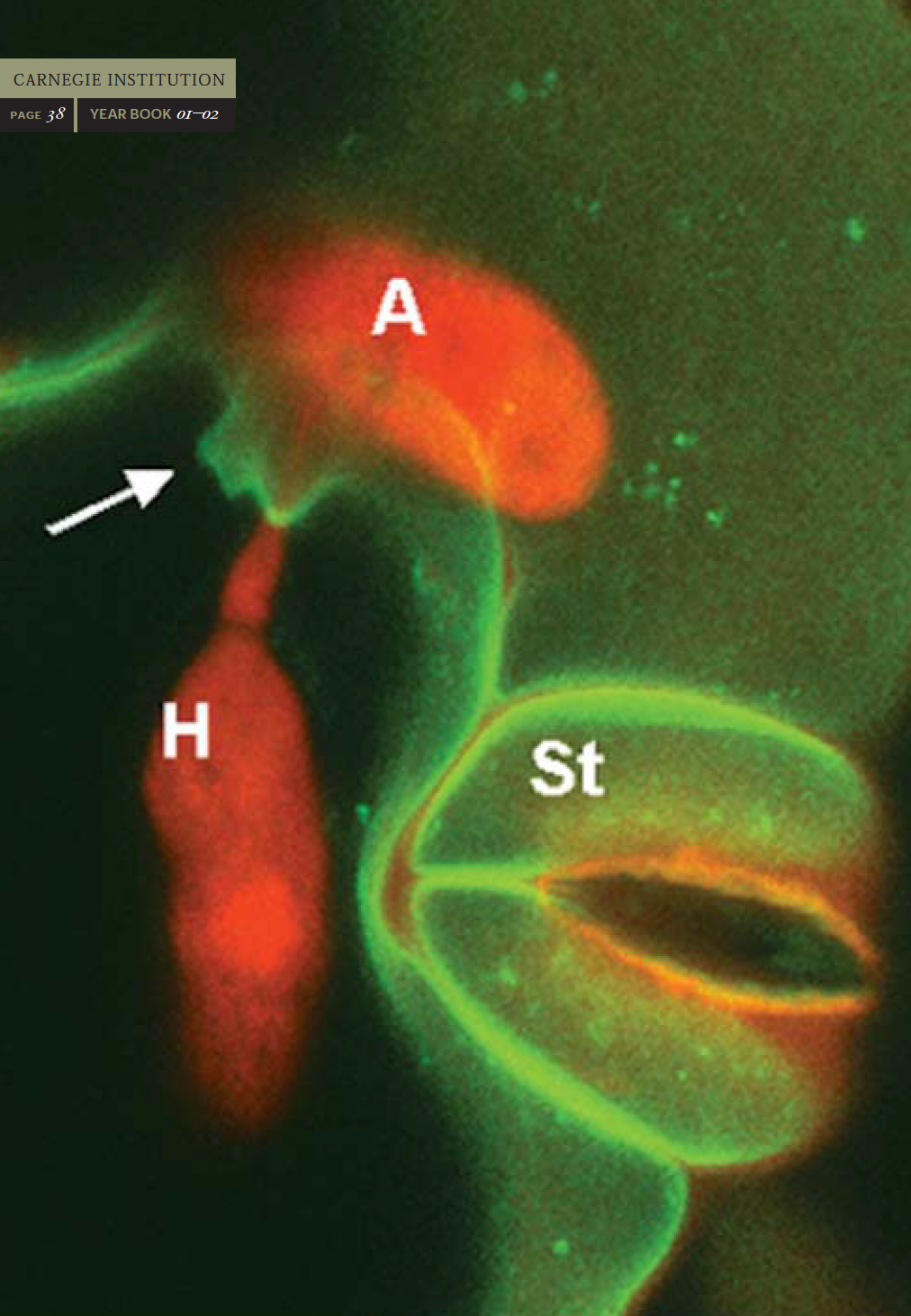
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THE DIRECTOR'S REPORT[1]

During the next 25 years, the world population is expected to increase by about 2.5 billion people, with most of this projected growth to occur in developing countries. By 2025, the food requirements in the developing world are anticipated to double. In contrast, there has been a progressive decline in the annual rate of increase in cereal yield so that, at present, the expected increase in yield is below the expected rate of the population increase. In addition, there are limited options for expanding the amount of land under cultivation to produce food crops without imposing undesirable environmental costs. Thus, the increased demand for food and fiber must be met primarily by enhancing production on land already under cultivation.

Coupled with the limitations of intrinsic yield and available land, there is a significant water problem. Of the accessible water, about 70% is already used for agriculture. Water systems are under severe strain in many parts of the world. Many rivers no longer flow to the sea, 50% of the world's wetlands have disappeared, and many major groundwater aquifers are being mined unsustainably, with water tables in parts of Mexico, India, China, and North Africa declining by as much as 1 meter per year. Approximately 40% of the world's food is produced on irrigated land, and 10% is grown with water mined from aquifers. There is growing competition for water from cities and industry, and agriculture is considered the "user of lowest value and last resort." The projected doubling of food production, therefore, must largely take place on the same land and consume less water. More effective management of water requires a series of institutional and managerial changes, in addition to a new generation of technical innovations that include advances in the genetic engineering of plants.

Photosynthetic CO_2 fixation by plants is associated with a large amount of water loss due to transpiration. Thus, to prevent desiccation-induced growth arrest and injury, most plants require adequate soil moisture. The production of one pound of cotton or grain, for example, requires several thousand pounds of water. Because water loss from plants is governed by physical principles, relatively little can be done at present to significantly modify the amount of water used by a particular plant species. However, a potentially major opportunity exists to increase the average water-use efficiency of agricultural systems by minimizing losses to pests and pathogens (i.e., insects, nematodes, fungi, viruses, and bacteria). It has been estimated that up to 40% of plant productivity in Africa and Asia, and about 20% in the developed world, is lost to pests and pathogens. Approximately one-third of the losses are due to viral, fungal, and bacterial pathogens, and the remainder is due to insects and nematodes. Much of the loss occurs after the plant is fully grown, when most or all of the water required to grow a crop has been invested. Reducing destruction from pests and pathogens, therefore, is equivalent to creating more land and more water.

Most plants have molecular mechanisms designed to resist pests and pathogens. Research directed toward understanding these mechanisms is in a period of rapid discovery, and as the understanding

[1] The first three paragraphs of this report are modified from C. R. Somerville and J. Briscoe, "Genetic Engineering and Water," *Science 292*, 2217. Copyright 2001 American Association for the Advancement of Science.

Left: This is a confocal image of a region of an *Arabidopsis* leaf that is being parasitized by the powdery mildew fungus. The plasma membrane of the plant cells is shown in green, and the fungal tissues are shown in red. Surprisingly, the plant plasma membrane, which is known to surround the fungal feeding structure (labeled H), is not labeled with the green fluorescent protein. This result suggests that the fungus has modified the properties of the plant plasma membrane, presumably as a mechanism for extracting nutrients from the plant cell. Label A is an appressorium, a fungal infection structure; St is a plant stomate, which is an opening that allows carbon dioxide to enter and water vapor to exit the plant leaf.

of resistance and susceptibility advances, it will become possible to transfer the resistant genes from one species to another. The success of the genetically modified insect-resistant corn and cotton plants grown on a large scale in the U.S. provides a compelling example of the feasibility of this approach. Plants engineered for pest and pathogen resistance could be distributed without cost to subsistence farmers in the developing world by the International Agricultural Research Centers or similar organizations. The benefits of such developments would be significant in terms of increasing income and food for the poor, reducing the demand for water, limiting land expansion for cultivation, and benefiting the environment.

The mechanisms by which plants resist pathogens are grouped into two types: race-specific resistance and nonhost resistance. Race-specific resistance refers to the observation that within genetically diverse populations of plants, some individuals may be resistant to certain races of pathogens that cause disease in other individuals. Where this phenomenon has been investigated in detail, it has been observed that the interaction between the host and the pathogen is usually controlled by one or a few genes in the plant and a corresponding set of one or a few genes in the pathogen (Fig. 1). In many cases it is now known that the genes that confer resistance in the plants encode receptor proteins that detect chemical signals released, directly or indirectly, by the pathogen. Activation of the receptors by a ligand stimulates a series of defensive actions by the plant that reduces the viability and growth of the pathogen. However, if the plant fails to sense the pathogen during the initial stages of the infection process, the pathogen becomes established and either kills the host and feeds on released nutrients or parasitizes it.

Powdery mildew is an economically important fungal disease that has been reported on more than 9,000 plant species. The fungus is an obligate parasite, which means that it can only grow on living host tissue (Fig. 2, Fig. 3). Recent studies in Staff Member Shauna Somerville's laboratory of the formation of the fungal feeding structure have exploited a collection of transgenic plants produced by former Stanford doctoral student Sean Cutler and Staff Associate David Ehrhardt. The plant lines express a series of different genes encoding a protein fused to the green fluorescent protein from the jellyfish *Aequora victoria*. Each of the fusion proteins is localized to a different sub-cellular compartment with the cells of *Arabidopsis*. The fluorescent fusion protein makes it possible to visualize changes in the organization of subcellular compartments following infection with the fungus. Postdoctoral associate Serry Koh used the trans-genic lines to discover that when the fungus inserts its feeding structure, or haustorium, into a plant

Fig. 1. Allelic variation in a single gene makes *Arabidopsis* resistant (left) or susceptible (right) to the powdery mildew fungus.

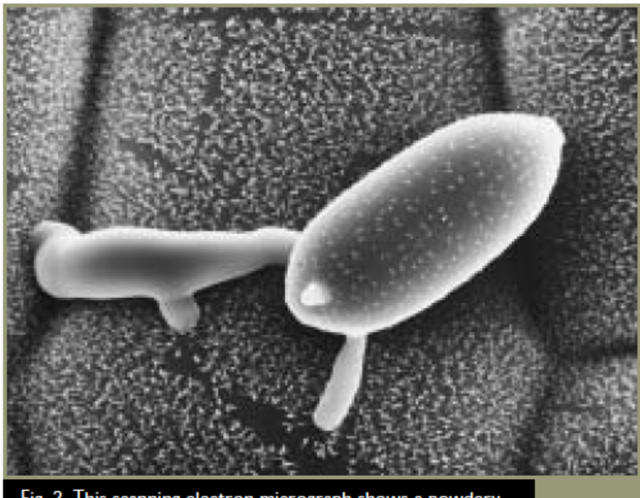

Fig. 2. This scanning electron micrograph shows a powdery mildew spore germinating on the surface of a plant cell. The spore has produced two hyphae, one of which is attempting to penetrate the plant cell wall.

cell it alters the targeting of proteins to the plasma membrane of the plant cell (frontispiece). This unusual phenomenon suggests that the fungus is actively controlling secretory processes within the plant cell. Perhaps, like the bacterial pathogen *Agrobacterium tumefaciens*, the mildew fungus has devised mechanisms for modifying cellular processes in its host.

As one way of understanding how *Arabidopsis* responds to infection by the powdery mildew pathogen, Shauna uses DNA microarrays to interrogate the effect of pathogen invasion on gene expression by the host. The microarrays are made by robotically spotting nanoliter droplets of DNA from as many as 14,000 different *Arabidopsis* genes onto glass slides, at very high density, in such a way that the DNA becomes affixed to the surface (Fig. 4). RNA extracted from plants at different stages of infection is chemically modified by adding a fluorescent tag. It is then hybridized to the array under conditions in which the mRNA corresponding to each gene binds to the corresponding DNA spot in proportion to its abundance in the RNA pool. Thus by measuring the fluorescence associated with each spot after hybridization, it is possible to infer how strongly expressed each gene was in the plant at the time of RNA extraction. To compare infected versus noninfected tissue, the RNA from each treatment is typically labeled with a differently colored fluorophore so that the hybridization of both samples can be measured simultaneously by examining fluorescence at different wavelengths.

The application of this technology to the analysis of the powdery mildew infection has revealed that the expression of many hundreds of genes is increased or decreased at various stages of the infection process. Furthermore, different accessions of *Arabidopsis* exhibit large differences with respect to which genes are induced or repressed as infection progresses. These results indicate that natural populations have substantial genetic variability for the regulatory processes involved in mediating the responses. To begin dissecting this complex regulatory network, Shauna and collaborators Fred Ausubel (Harvard University) and

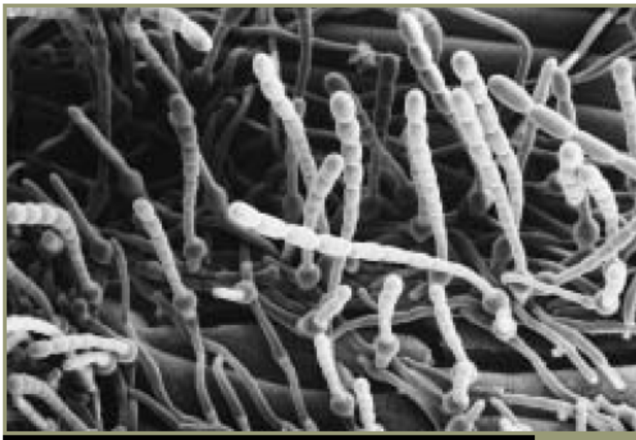

Fig. 3. This is a scanning electron micrograph of the surface of a leaf that has become infected with powdery mildew. The leaf is covered with a mat of hyphae from which vertical stalks have emerged and are releasing a new generation of spores.

Xinnian Dong (Duke University) are using the microarrays and a similar technology called gene chips, developed by Affymetrix, to characterize the effects of mutations on the disease response. The world academic community has collectively identified several dozen genes in which mutations cause altered responses to pathogens. Shauna and collaborators are now using the microarrays and Affymetrix gene chips to characterize the effect of each of these previously characterized genes on the pattern of expression of all of the other genes in the genome. Their goal is to develop an understanding of the overall structure of the network of regulatory controls that govern the outcome of a plant-pathogen interaction.

Gene chips and microarrays are broadly useful, and several other groups within the department, and many groups from other institutions, have benefited from the availability of the knowledge represented within Shauna's group and from the availability of the instruments she acquired through large grants from the U.S. Department of Energy and the National Science Foundation. During the past three years, more than 100 people have visited the department to learn about DNA microarray technology. Fortunately, the technology has become more widespread and the flux of visitors to the department for this purpose has

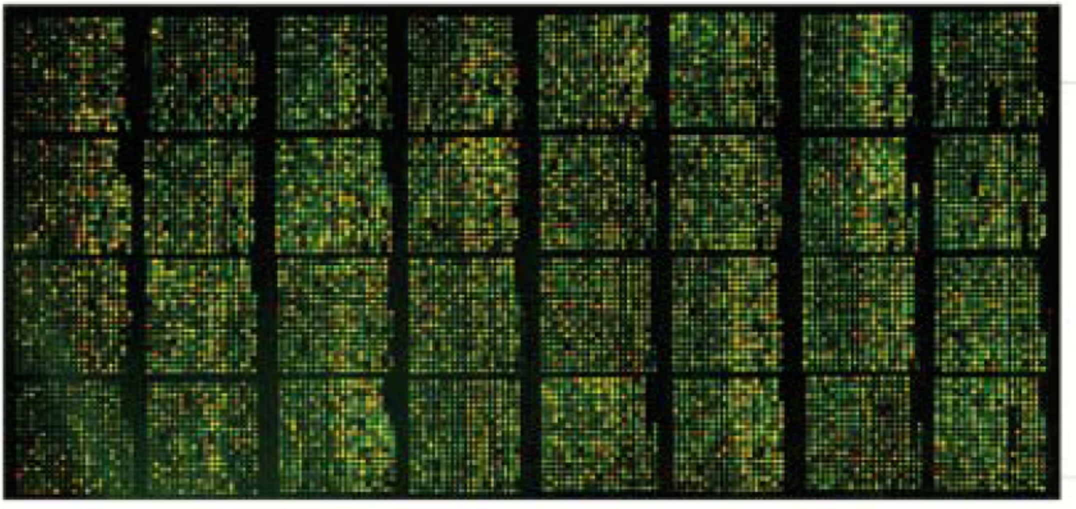

Fig. 4. This enlarged image of a DNA microarray contains approximately 11,000 spots of DNA in 2-square centimeters. The array has been hybridized to two RNA samples that were labeled with different fluorophores. The spots in which the signal from both fluorophores are similar are labeled yellow, and those in which the signal from one sample was stronger or weaker than the other are labeled red and green, respectively.

subsided. The challenge now is to move beyond the technical challenges of producing data to interpreting the relatively vast amounts of information that can be produced by the technology. Shauna and her collaborators have already amassed approximately 13 million measurements, most of which are available on the Internet at http://www.arabidopsis.org/info/2010_projects/comp_proj/AFGC/index.html.

Although race-specific disease resistance may be useful in natural environments, it is of limited value in agriculture because the large stands of genetically pure crops lead to strong selection for the evolution of virulent forms of pathogens. While it may require 7 to 10 years to produce a new pathogen-resistant plant variety by conventional breeding methods, the resistance is usually breached within 3 to 5 years after the first commercial use of a new variety because new races of virulent pathogens evolve. There is, therefore, substantial interest in understanding the mechanisms associated with nonhost resistance. The concept of nonhost resistance is, perhaps, best understood by example. Whereas wheat and barley are highly sensitive to infection by the powdery mildew fungus, the closely related species of maize and rice are not susceptible to the mildew. Why this is the case has long been debated. Is it because maize and rice fail to produce some substance that is required for the mildew to grow, or, alternatively, is it because they possess some unusually effective defense mechanism that actively prevents the fungus from growing? Because there are no mutants that convert a nonhost to a host or vice versa, it has been impossible to determine how many genes are involved in nonhost resistance or what the nature of the mechanism is.

Several years ago, Shauna and Hans Thordal-Christensen, a sabbatical visitor from Risø National Laboratory in Denmark, initiated a novel approach to this long-standing problem. Hans inoculated mutagenized *Arabidopsis* plants with the powdery mildew species that normally infects barley, but not the nonhost *Arabidopsis*. Although

there were no plants found that would fully support the growth of the fungus, careful examination revealed several *Arabidopsis* mutants in which the fungus exhibited a small amount of growth. This raised the possibility that these mutants had impaired a mechanism that normally prevents the barley powdery mildew from growing on *Arabidopsis* and that the corresponding genes represent components of a mechanism that actively impedes the growth of the fungus.

Subsequently, Stanford graduate student Monica Stein isolated mutations at three separate loci that exhibit similar effects (Fig. 5), and colleagues in Paul Schulze-Lefert's department at the Max Planck Institute in Cologne isolated similar mutants. Collaborative work is now under way to characterize the corresponding genes in the hope that knowledge of the gene structure will reveal the first unambiguous insights into the mechanisms associated with nonhost resistance. It is an exciting moment in that an intractable and important problem has begun to yield.

Another important and potentially related recent development was the discovery by postdoctoral fellow John Vogel that mutations in a gene encoding a probable pectate lyase resulted in high levels of resistance to powdery mildew in *Arabidopsis*. Pectate lyase is an enzyme that cleaves polygalacturonic acid, one of the acidic polysaccharides that are principal components of plant cell walls. Because cell walls provide strong inelastic barriers to pathogen penetration, it has long been believed that the chemical composition of cell walls must be a factor in disease susceptibility. To reach cells, fungal pathogens must secrete cell-wall-degrading enzymes that break down the cell wall polysaccharides. It has been proposed, notably by Peter Albersheim and collaborators, that the release of cell wall fragments by fungal enzymes could create highly specific chemical signals that could be used by plants to sense the presence of the pathogen. Thus, the implication of a pectate lyase gene in disease resistance is compatible with a well-known hypothesis. Nevertheless, it is not yet apparent what the role of the plant pectate lyase gene is in

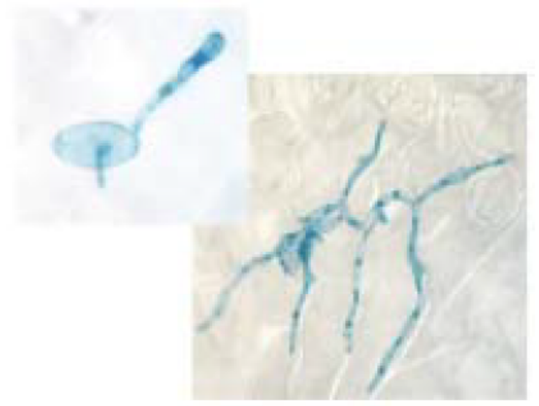

Fig. 5. Spores of the barley powdery mildew pathogen do not develop on wild-type *Arabidopsis* (left) but progress to later stages of the life cycle on an *Arabidopsis* mutant that exhibits reduced nonhost resistance (right).

conditioning resistance. One possibility is that the loss of the pectate lyase function leads to the presence of a polysaccharide in the cell walls that generates a chemical signal when cleaved by fungal enzymes. To explore this idea, postdoctoral associate Ted Raab used the synchrotron source at the Lawrence Berkeley Laboratory to carry out Fourier Transform Infrared Spectroscopic studies of intact cell walls from mutants and wild types. These studies indicated that the mutant walls have a different composition or structure from the wild type. However, additional studies, done in collaboration with the group of students and postdocs in my laboratory who are studying the structure of cell walls, will be required to define the precise difference. This is a potentially exciting discovery in the context of cell wall biochemistry because it may suggest a possible biological function for some of the highly complex polysaccharides that are found in plant cell walls. Coincidentally, because the mutation confers resistance to all available races of powdery mildew, it may be a component of a nonhost resistance mechanism.

Shauna's research program highlights some of the complex technical and conceptual challenges associated with understanding how plants and their pathogens interact. The difficulties of understanding biological processes are greatly amplified

Fig. 6. Plant Biology staff pictured here are (left side, bottom to top) Zhi-Yong Wang, Matthew Evans, Susan Thayer, Katrina Ramonell, Shauna Somerville, and Lorne Rose. First row, seated, are Marjorie Santamaria, Chunxia Xu, Michelle Facette, Heather Youngs, Erin Osborne, Miguela Osbual, Devaki Bhaya, and Marc Nishimura. Sitting and standing, right side, top to bottom, are Trevor Swartz, Olivier Vallon, Winslow Briggs, Dafna Elrad, Paul Sterbentz, Lukas Mueller, and Chris Somerville. Second row, on steps, are Kathryn Bump, Peifen Zhang, Julie Tacklind, Dominique Bergmann, Susan Cortinas, Kathryn Barton, Jennifer Milne, and Wolfgang Lukowitz. Third row, seated, are Suparna Mundodi, Tanya Berardini, Jeffrey Moseley, Khar-Wai Lye, Rachael Huntley, and Dario Bonetta. Fourth row, seated, are Joshua Gendron, Theodore Raab, Farhah Assaad, Florent Mouillot, Chung-Soon Im, and Dorianne Allen. Fifth row, seated, are Yigong Lou, Jun-Xian He, Shijun Li, William Wong, Soo-Hwan Kim, Daniel Yoo, Wirulda Poothakam, and Eirini Kaiserli. Back row, standing, are Rashmi Nunn, Gabe Lander, Nadia Marinova, Zhaoduo Zhang, Nick Moseyko, Nakako Shibagaki, Brenda Reinhart, Pedro Pulido, John Jacobson, Mike Ruvolo, and Glenn Ford.

when studying how two organisms interact. However, the powerful new technologies employed in her program have allowed progress on many fronts, and I believe that we will eventually understand enough about the major pathogens to minimize future losses of food, feed, and fiber that will be needed by the expanding population. Shauna's program also exemplifies the effective application of methodological synergies that we are creating among the research groups that currently make up the department. Her lab provides microarray expertise to the other groups within the department. Sue Rhee's group provides bioinformatics tools and expertise needed to store and use the large amounts of data generated with genomics tools. Dave Ehrhardt's lab provides expertise and leading-edge tools in cell biology, and my lab has provided expertise in analytical and biochemical methods for cell wall analysis. One of my goals for the department is to try to ensure that a similar network of expertise and overlapping interests extends to and from each of the research groups within the department. I believe that discoveries arise at such intersections.

—Christopher Somerville

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[1] From August 1, 2001
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[3] From October 1, 2001
[4] From August 31, 2001
[5] From March 1, 2002
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[7] From September 7, 2001, to October 2, 2001
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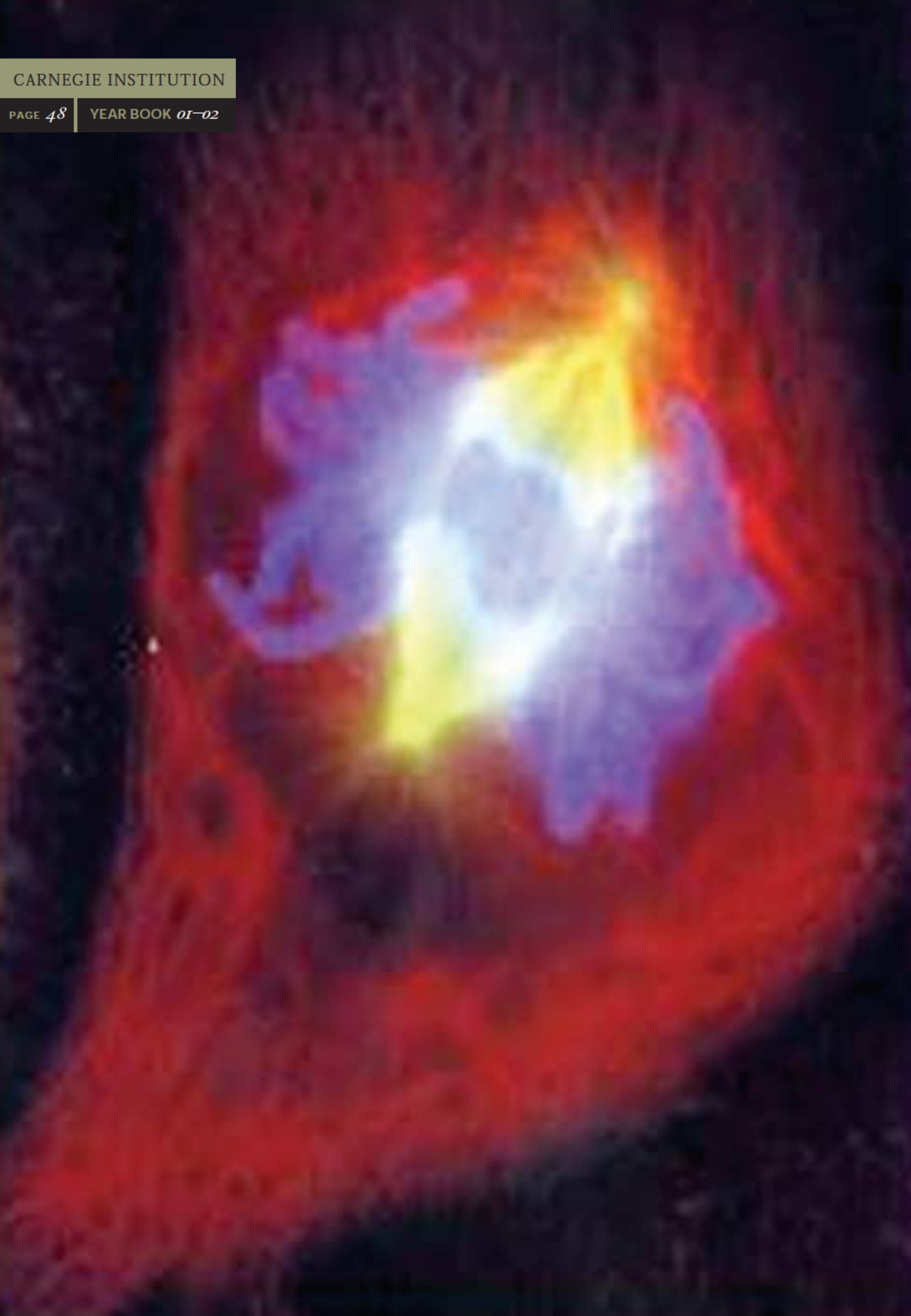

THE DIRECTOR'S REPORT

Modern society requires that myriad commodities and individuals be continuously transported between destinations throughout the world. The remarkable mechanisms that daily bring us fresh fish from halfway around the globe move cargo rapidly and efficiently while minimizing accidents, hazards, and even deliberate sabotage. During the last year, we have been reminded that transportation is always a tradeoff between speed and safety. Nature, likewise, has achieved an exquisite balance in the movement of diverse materials within living cells. Organisms, like societies, depend on the orderly arrival of diverse cellular components at their appropriate destinations and are equally subject to the consequences of delay. A security lapse can result in the introduction of a pathogen. Deciphering such highly evolved controls occupies a significant number of investigators within the department.

The movement of chromosomes toward the two poles of the mitotic spindle during cell division is precisely regulated—a single error in segregation would misprogram or kill the daughter cells. Doug Koshland's group studies several aspects of chromosome movement. The researchers have deciphered new components of centromeres, the specialized chromosomal sites where microtubules attach in an oriented fashion to the two sister chromatids. In addition, they have characterized key molecules that release the attachments between the sisters and cause them to begin moving apart. Much recent study has focused on molecular complexes known as cohesins and condensins, which contain SMC proteins, a class of proteins discovered in the Koshland lab. Both types of complexes help fold the immensely long chromatin fibers within chromosomes into a manageable size and structure. Cohesins bind in a regular manner about every 12 to 13 kilobases of DNA away from the centromere, and more densely within it. Here they may position and control the action of the condensins in packaging the chromosome fiber into regular loops and folds that help regulate chromosome movement and function.

Yixian Zheng's lab studies the key cellular machinery that makes ordered chromosome movement possible. The mitotic spindle (frontispiece) assembles largely from tubulin monomers just prior to mitosis, binds to chromosome centromeres, and mediates chromosome separation during anaphase. Zheng's lab recently discovered that the nucleus sends a signal to help initiate spindle formation at the time the nuclear membrane breaks down. The message is carried by the small nuclear protein Ran, a protein that normally acts to regulate the movement of materials from the cytoplasm into the nucleus. Additional studies by Zheng's group have uncovered more unexpected parallels between nuclear import and spindle formation.

The regulated polymerization of microtubules at the cell's recently separated centrosomes is ultimately responsible for spindle formation. Zheng continues to analyze how the pericentriolar material of centrosomes controls microtubule nucleation at the time of spindle assembly. Her group has determined the structure and function of proteins that make up the gamma-tubulin ring complex (gammaTuRC), which Zheng showed previously to represent the cell's basic microtubule nucleation device. Understanding how gammaTuRC complexes are organized and activated in diverse biological contexts is likely to be the key to determining how many other cellular components in addition to chromosomes are transported within cells.

Left: The spindle assembly is shown as yellow in this image of an early stage of cell division. (Image courtesy Yixian Zheng.)

Some of the most interesting biological movements take place within growing eggs. Joseph Gall and his colleagues have exploited the enormous size of developing amphibian oocytes to study how cells regulate the movement of key molecules that are required to synthesize and process gene transcripts within the nucleus. Many of the proteins and RNAs involved in these events are found not only on the chromosomes, where they function to "read" the genes, but also in enigmatic structures known as Cajal bodies within the nucleus of the developing oocyte. As part of their program to understand the structure and function of Cajal bodies, Gall's group is focusing on the movement of specific proteins and RNAs as they enter and leave Cajal bodies (Fig. 1). Gall hopes to decipher whether Cajal bodies function as staging areas, storage depots, catalytic complexes, or in some other manner that can explain their widespread presence within cell nuclei.

Staff Associate Jim Wilhelm studies a complex of proteins and RNAs that controls the movement, storage, and utilization of oocyte RNAs in *Drosophila* (Fig. 2). *Drosophila* eggs have a special transport requirement because nearly all their cytoplasmic contents are synthesized outside the egg in nurse cells and subsequently delivered through channels known as ring canals. Two such RNAs, derived from the genes *bicoid* and *oskar*, are localized at the head and tail of the egg, respectively, where they play critical roles in patterning the embryo along its head-to-tail axis and in specifying germ cells. Wilhelm and colleagues have identified a complex containing seven proteins, *oskar* mRNA, and likely additional components, which is involved in transporting and localizing RNAs to their appropriate destination. The transport complexes are thought to associate with molecular motors that move them along cytoplasmic tracks defined by cytoskeletal elements such as microtubules or microfilaments. Many of the proteins are also expressed in nerve cells and other tissues outside the ovary, leading Wilhelm to suspect that the machinery used to transport and localize mRNAs in developing eggs is also important in many other cells.

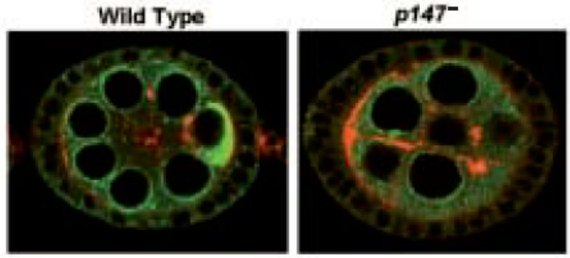

Fig. 2. The left panel is a wild-type egg chamber stained for Trailer Hitch, a protein present in the oskar mRNA transport complex. Note that it accumulates at the posterior pole of the oocyte. When another component of the complex, p147, is mutated, Trailer Hitch no longer accumulates in the oocyte, indicating that p147 is required for Trailer Hitch transport (right panel). (Image courtesy James Wilhelm.)

Rachel Cox, a postdoctoral fellow in my laboratory, has found that regulated transport is used to assemble many of the major constituents of *Drosophila* eggs. Most organelles of the young

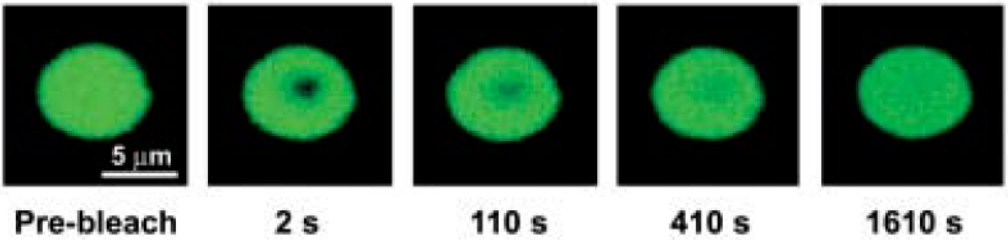

Fig. 1. This series is an experiment to illustrate the dynamic nature of macromolecules in a Cajal body (inside a living nucleus). The Cajal body in the first panel is green because it contains a fluorescent RNA molecule. In the second panel, a brief pulse of high-intensity laser light has bleached a small spot inside the Cajal body. Over a period of 1610 seconds the bleached spot disappears as new fluorescent RNA molecules move into the Cajal body. This experiment gives an idea how rapidly molecules enter and leave the Cajal body. (Image courtesy Korie Handwerger.)

Drosophila oocyte, including mitochondria, Golgi elements, centrosomes, and endoplasmic reticulum (ER) vesicles, are not inherited by simple fission of a precursor germ cell. Instead, they are transported from within sibling germ cells that are located with a 16-cell germ line cyst, the progenitor of a single oocyte. The transported organelles move into the oocyte in a large mass known as a Balbiani body, remain for some time near its nucleus, and later disperse throughout the oocyte (Fig. 3). Moreover, RNAs, including the oskar mRNA studied by Wilhelm, transiently associate with the Balbiani body, which may play some role in facilitating RNA movement, possibly accompanied by some mitochondria, to the oocyte posterior. Balbiani bodies very similar in appearance are found in young frog, mouse, and human eggs, suggesting that evolutionarily conserved transport pathways may assemble egg cytoplasm in many species.

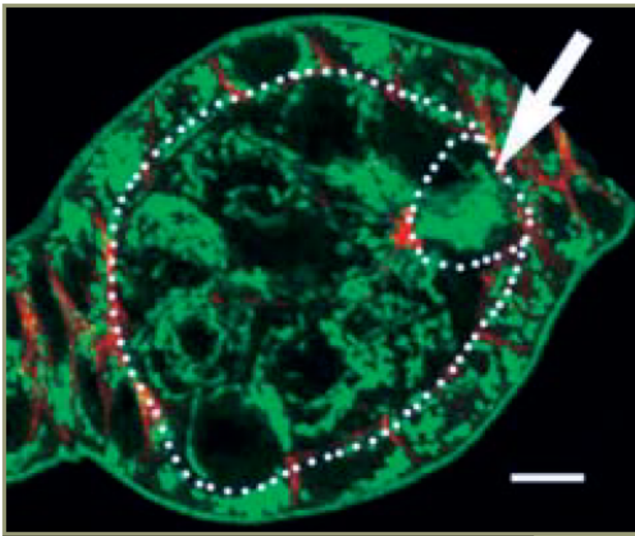

Fig. 3. *Drosophila* ovarian follicles consist of an interconnected 16-germ cell cyst (large dash circle) surrounded by somatic follicle cells. Mitochondria are labeled in green, the cell membranes in red. A subset of mitochondria from 15 of the germ cells, which function as helper nurse cells, moves into the 16th cell, which becomes the oocyte (small dash circle). These mitochondria form a tightly packed round structure known as the Balbiani body (arrow), which consists of mitochondria, Golgi, ER, centrosomes, and various RNAs and proteins (scale bar = 5μm). (Image courtesy Rachel Cox.)

News of the Department

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THE DIRECTOR'S REPORT:
A Revolution in Astronomy

Revolutions can be hard to recognize; we often do not realize one is happening until it is almost over. We think we are dealing with minor readjustments in the established order even after the king has lost his head and the tumbrels are rolling through the streets. The inevitability of change seems apparent only in retrospect, not while it is happening. Predicting scientific revolutions is particularly difficult, and not for those who are afraid to look ridiculous. However, since it is important to know where we are heading—especially in astronomy, which depends on large investments of facilities taking years to build and decades to exploit—I will venture a prediction: astronomy is at the beginning of a revolutionary change, of a magnitude that is seen only once every few hundred years.

This change is the ending of a path, which itself began with a pair of revolutions. The first occurred when Galileo turned a telescope toward the sky and discovered that the heavens were not the immutable crystalline spheres of medieval astronomy, but rather a part of the same natural order that existed on Earth. For three hundred years astronomers explored the heavens Galileo discovered, mapping and describing their contents.

Mapping and describing are essential first steps in any science, but by themselves they are only geography, because they do not explain what is observed. George Ellery Hale changed all that, and started the second revolution. Hale, with some help from like-minded astronomers, was the founder of astrophysics—the application of physical science to the cosmos. He realized that the transformation wrought by Galileo was incomplete. The cosmos was now part of the natural order, but it was not yet (with the exception of Newtonian gravity) fully a subject for the natural sciences of physics and chemistry, and was therefore not understandable. Hale also realized that the enterprise of understanding the universe would require great resources—of people and particularly of telescopes—and he found a succession of philanthropists, most notably Andrew Carnegie, to support his vision. Hale made modern astronomy happen; he set the course, and found the means to pursue it. The history of post-1900 astronomy, which is in large part the history of Carnegie astronomy, is the gradual realization of Hale's vision.

It has been a long road—four hundred years of exploring and explaining. Roads that long begin to seem endless: a never-ending pursuit of ever more phenomena. Until recently, there was nothing in the progress of astronomy to contradict this view: new mysteries appeared faster than old ones could be solved, and all advances came painfully slowly. One example: 70 years ago Hubble set out to measure the scale of the universe. Only now, after 70 years of labor by Hubble, Baade, Sandage, Freedman, and others, has that scale—the Hubble Constant—been determined to better than 20 percent.

Left: Observatories Starr Fellow Paul Martini, Staff Member John Mulchaey, and colleagues found some surprises about galaxy clusters. This false-color image of the Abell 2104 cluster of galaxies was taken with NASA's Chandra X-ray Observatory, then overlaid on an optical image taken with Carnegie's 6.5-meter Walter Baade telescope at Las Campanas, Chile. It reveals X-ray emissions produced both by hot gas (the dense blue area) and by accretion of dust and gas onto supermassive black holes (the smaller blue patches on the outer edges of the image). The number of active supermassive black holes found in this cluster is six times the amount found using other techniques. The result suggests that active black holes are much more common in clusters of galaxies than was previously believed. (Image courtesy NASA and John Mulchaey.)

The Changing Cosmic Landscape

Lately, however, astronomers have begun to notice that the cosmic landscape is changing. Large, coherent pieces of a complete picture of the universe seem to be falling into place. There may be huge surprises ahead that will completely undermine our neat emerging picture. However, absent such surprises, there is reason to hope that a few decades will suffice to produce a rather complete understanding of the universe "in the large" (more on this qualifier later). Three things have brought us to this point. One is, of course, the perseverance of generations of astronomers, who have steadily if slowly worked their way through layers of questions. In addition, two technical advances have accelerated progress. One is the improvement in the capabilities of telescopes, instruments, and detectors. Telescopes have grown steadily larger. Even more important, though, has been the increase in efficiency by a factor of one hundred that came when electronic detectors replaced photographic plates, and the similarly large multiplexing advantage of wide-field cameras and multiobject spectrographs. (Increasingly effective telescopes and instruments operating at other wavelengths, from the radio to gamma rays, are part of this progress, too.) The second technical advance has been in computers, whose power has become sufficient to take on the most complex astrophysics. Advances in observations and in theory leverage each other; theory guides and explains observations, observations guide and validate theory. Without both, progress stagnates.

Although our understanding of discrete astronomical phenomena has grown steadily, it is the rapidly increasing connections between these islands of understanding that is new, particularly on cosmological scales. The word of the year in cosmology is "concordance." Several independent kinds of observational data are yielding consistent evidence for a universe with about two-thirds of its mass-energy in the form of what has become known as dark energy, which may be the cosmological constant of Einstein's gravitational theory. About one-third of the mass-energy is believed to be in the form of "cold, dark matter"—a type of matter that only very weakly interacts with ordinary matter (except by gravity). Just a few percent of the universe consists of the ordinary matter of which people, planets, and stars are composed. We do not yet know what dark energy and dark matter are; but we think we know how they behave.

Given a universe made of such stuff, theoretical models can now explain how it evolves, growing structures on all scales which eventually coalesce into galaxies, clusters of galaxies, and superclusters. Once protogalaxies form, we are beginning to understand how they grow and evolve into the types of galaxies that we see today. The structure of galaxies—their gas, stars, dark matter, massive central black holes, and their dynamics—are also becoming clear. Although the birth and death of stars are still poorly understood, their structure and evolution between these end points are rather well understood. The history of the chemical elements is also known in broad outline. And now, after decades of failure, new extrasolar planetary systems are being discovered almost weekly, and a picture of planet formation as a natural component of star formation is emerging.

It would be misleading to claim that we now have a clear understanding of the big picture, but much of it is clear and seems to fit into a consistent whole. It is the fact that our detailed knowledge of particular objects can be fit into a larger framework derivable at least crudely from first cosmological principles that is new and gives us a new sense of confidence.

Despite this progress, it is not yet time to retrain astronomers for more useful professions. It is essential to test the concordance view of a universe filled with dark energy, cold dark matter, and a sprinkling of ordinary matter, and fill in the other gaps of our knowledge. The Magellan telescopes and others like them were built for filling in these gaps, which include the following:

Galaxy formation: How and when did the first small pregalactic lumps form in the expanding, cooling universe? How did they

fragment to form stars, and coalesce to form larger galactic systems?

Galaxy evolution: How have galaxies changed since the epoch of formation? To what extent have galaxy-galaxy mergers or other interactions with the extragalactic environment effected changes? What has been the history of star formation within galaxies, and the formation history of the chemical elements? How do massive black holes form in the centers of spheroidal galaxies, and what role do they play in galaxy evolution?

The formation of stars and planets: How do intragalactic gas clouds fragment to form stars? How do the gas disks orbiting young stars evolve into planetary systems? What are the properties of those planets; do any harbor life?

Supernovae and the Cosmic Expansion

Many of these questions are the targets of major new research programs using the Las Campanas telescopes. The concordance picture of cosmology rests, in large part, on the use of supernovae as measures of the cosmological expansion rate. Supernovae of type Ia (Fig. 1)., which are exploding white dwarf stars, are particularly good standard candles, whose photometric properties allow a distance determination to better than 10%. However, stars and stellar populations evolve, and over the same timescales on which the cosmic expansion rate changes. Thus, an evolution in supernova properties could mimic the observed evolution in the expansion from which we deduce the dark energy and dark matter content of the universe.

Wendy Freedman, Barry Madore, Eric Persson, Mark Phillips, Hubble Fellow Mario Hamuy, and collaborators at several other institutions are beginning several programs to better characterize both the intrinsic properties of supernovae and their cosmic expansion. It was Phillips's earlier work on the luminosities of supernovae that enabled their use as reliable standard candles. However, until one can determine that this method is not even subtly biased by variations in the stellar populations that give rise to the supernovae, one cannot rely on them as cosmological probes. A massive, detailed study of nearby type Ia supernovae, using the du Pont and Swope telescopes, is intended to answer this question.

Fig. 1. Type Ia supernovae, such as SN98bu in the nearby galaxy M96, are the most effective tools for studying the dynamics of the universe and thus measuring the dark matter and dark matter content.(Photo courtesy N. Suntzeff)

Systematic problems aside, the quality of existing data is inadequate. The same group is embarking on a program to observe type Ia supernovae at high redshifts (0.2 to 0.6), the range over which a dark energy component begins to dominate the dynamics of the universe. They are establishing a restframe I-band Hubble diagram as free as possible from systematic errors in the type Ia supernova distances using the new infrared camera, PANIC, built by Eric Persson. With these data, it will be possible to confirm and better understand, or refute, the apparent low brightness of high-redshift supernovae from which the existence of dark energy has been deduced. The ultimate goal is to achieve discrimination between competing models for the expansion of the universe and the geometry of space-time.

Probing Cosmic Gas

The ability of the concordance model to explain the growth of structure in the universe is one of the great recent advances in astronomy, but our view of that structure is limited largely to the galaxies. Gas, however, is an equally important component of the matter content of the universe—increasingly so at earlier epochs—and the gas is much less well observed. Michael Rauch is conducting a survey with the Magellan telescopes to probe the properties of high-redshift galaxies and the pervasive intergalactic gas from the absorption spectra of gravitationally lensed quasars or close groups of quasars. The light from distant quasars is partly absorbed by the gaseous matter between us and the quasar in a way that depends on the temperature, density, motion, and chemical composition of the gas. Thus, the spectrum of the background light source contains a detailed record of all the material between us and the quasar, not unlike a drilled core.

Gravitational lensing produces multiple images of quasars, which are separated by angles large enough to be resolved from the ground (Fig. 2).

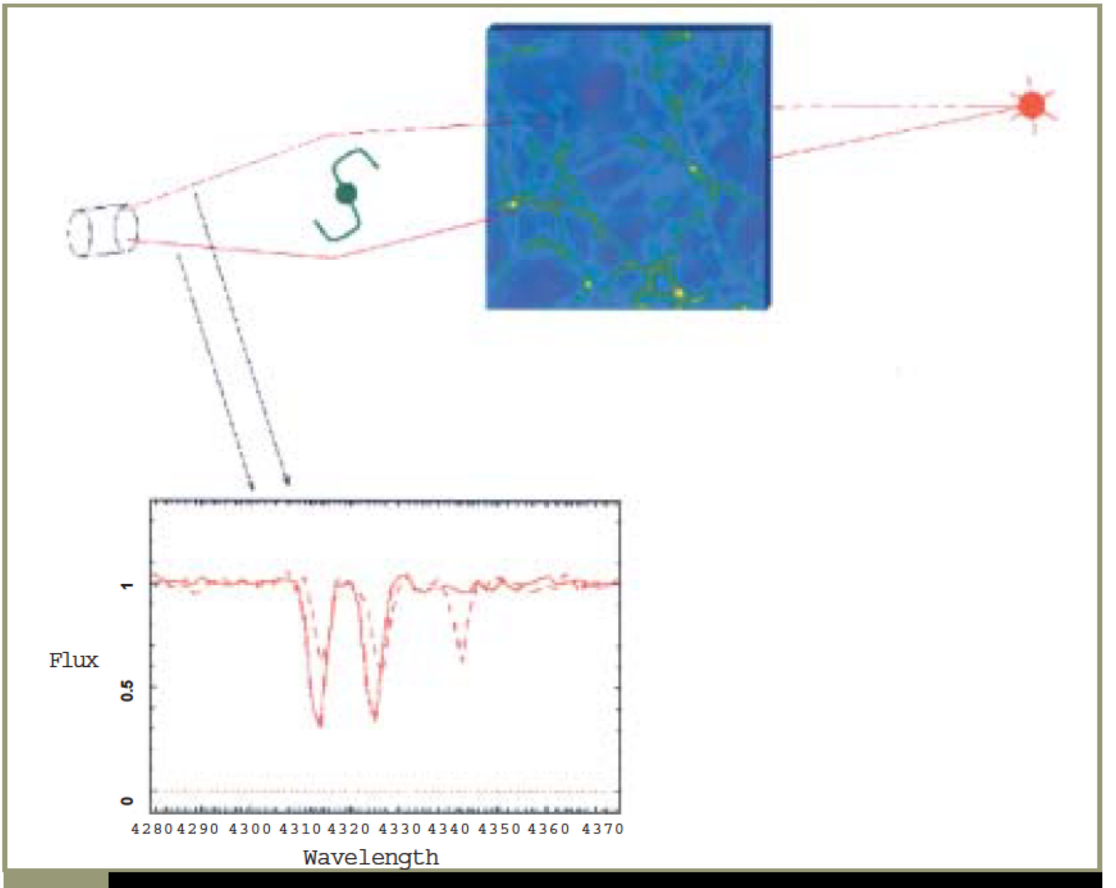

Fig. 2. This figure shows a "slice" of the universe, represented by an image (top square) from a cosmological simulation by Professor Mike Norman (UCSD).It is illuminated by a background quasar (the red star symbol on the right). Gravitational lensing by an intervening galaxy (green) diverts the light from the quasar such that the terrestrial observer (telescope, left) is seeing multiple, slightly displaced images of the quasar. The light from each image has traveled along slightly different paths through the universe to us. The intergalactic gas in the slice has imprinted an absorption pattern onto the quasar spectrum (inset below, showing spectra—solid and dashed lines—obtained with the Magellan II telescope), telling us about the physical conditions in the gas. By comparing the absorption lines along the different lines of sight to the quasar, it is possible to reconstruct the distribution of matter in the slice as a function of redshift and spatial separation between the light beams.

Fig. 3. The IMACS spectrograph nears completion at Santa Barbara Street. When installed on the Baade telescope, it will be the most powerful survey spectrograph in existence.

Each image is essentially an identical picture of the quasar, but the path the light takes from the quasar to us is slightly different in each case, and so the light beams probe slightly different regions of space. By taking spectra of the multiple images, one can learn about the texture of galaxies or gas along the lines of sight as a function of distance between the sight lines, and this yields a (sparsely sampled) three-dimensional picture of the universe toward that quasar. The superb image quality of the telescopes, with the superior seeing at Las Campanas, enhances the light-gathering power and spatial resolution provided by the gravitational lenses further, making the Magellan telescopes probably the best instruments in the world for this sort of research.

Galaxy Evolution

The evolution of galaxies has long been a preoccupation of Carnegie astronomers. Two phases of galaxy evolution are the subject of major surveys with the IMACS spectrograph (Fig. 3) on the Baade telescope (Magellan I). A key issue in the hierarchical picture of galaxy formation is determining the epoch at which the most massive galaxies are assembled by the mergers of smaller objects. The Las Campanas Infrared Survey, undertaken on the du Pont telescope by Pat McCarthy, Eric Persson, Carnegie Fellow Paul Martini and others, was designed to find the progenitors of today's massive elliptical galaxies at redshifts between 1 and 2, when they were about half their present age (Fig. 4). The collaboration is now beginning to use the Magellan telescopes to obtain spectroscopic observations of the objects found in the du Pont survey. These observations will establish whether these objects are, indeed, the long-sought young ellipticals, and determine how they are distributed in the universe and how they have evolved.

Alan Dressler, Carnegie Fellow Michael Gladders, and I plan to use IMACS to do four-dimensional tomography of forming clusters of galaxies. Observations of galaxies at high redshifts have provided snapshots of galaxy populations at earlier epochs, which demonstrate that galaxies evolve under the influence of their environments. However, such snapshots are insufficient to follow

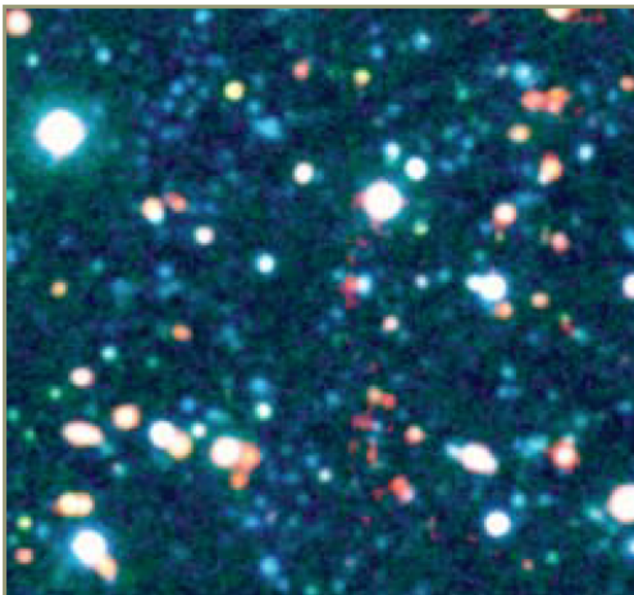

Fig. 4. In this true-color optical/infrared image from the Las Campanas Infrared Survey, the reddest objects are probably massive galaxies dominated by old stars, seen at half the present age of the universe. Blue objects are nearer galaxies with continuing star formation.

the evolutionary paths of individual galaxies, or to determine the processes that drive that evolution. Although one can sample equivalent populations of galaxies at different redshifts, and therefore different epochs, the available samples are too sparse to allow one to connect the dots representing successive evolutionary phases. The massive data set, which will be provided by the unique wide-field capabilities of IMACS, should allow one to do so, and thus trace the evolutionary history of galaxies as they fall into clusters and change under the influence of the environments they encounter.

The Evolution of Elements and Chemicals

The history of the chemical elements is a fundamental datum as well as an important tracer of galaxy evolution. The Magellan telescopes will allow us to make significant progress in understanding the astrophysical origin of the elements, in addition to galactic chemical evolution. An important tool for understanding chemical evolution and nucleosynthesis is to study chemical enrichment in a variety of environments. For detailed abundance studies of individual stars, Magellan provides a tremendous leap out of the galaxy, reaching much of the Local Group with the MIKE (Fig. 5) and IMACS spectrographs—in particular the Large and Small Magellanic Clouds and the closest dwarf spheroidals. For the closest Local Group galaxies, the composition of the old red giant stars will be accessible and will reveal the detailed chemical history.

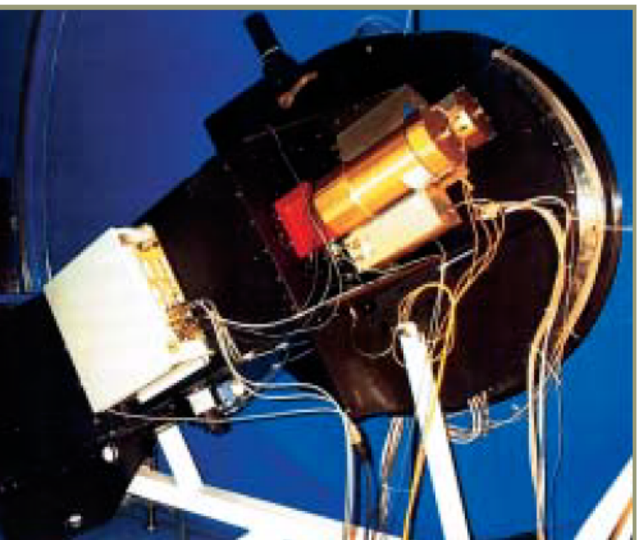

Fig. 5. The MIKE Echelle spectrograph will probe the history of the chemical elements in nearby galaxies and the formation of gas structures in the early universe. It will also be used to search for dynamical signs of planetary systems around nearby stars.

George Preston, Steve Shectman, Andy McWilliam, and Ian Thompson are using the Magellan Echelle spectrograph (MIKE) to continue and expand their ongoing study of the most metal-poor stars known in the galaxy; some made from the ejecta of single supernova explosions. The chemical compositions of these objects will tell us about the variety of supernova nucleosynthesis during the earliest phase of chemical enrichment, and set limits on pregalactic element synthesis. For a subset of these stars, it will be possible to measure the abundance of the radioactive element thorium, which will allow us to determine directly the stellar age and a lower limit for the age of the galaxy.

Knowledge of the origin and evolution of our own galaxy will be greatly improved by detailed chemical abundance studies of stars in the halo, disk, and bulge, which McWilliam is planning. We may learn about the role of accretion and galactic collisions in building the halo, and the properties and history of chemical enrichment in the bulge. Detailed chemical-composition studies of stars in galactic disk clusters have been mostly limited to the solar neighborhood. Magellan will permit studies of these clusters to the outer limits of the disk.

Next Challenges

It is reasonable to expect that a decade or two of such work, at Magellan and the other large new telescopes, will answer many of the questions posed above; but it is already clear that it will not answer all. Some projects will just take too long with the light-gathering power of 6- to 10-meter telescopes. Type Ia supernovae, for example, will be observable out to redshifts of about 1, but no farther. Observations to redshift 1 can reliably

detect the effects of dark energy, but not necessarily discriminate among various theories for its nature. Magellan-class telescopes can probe the chemical history of the nearest galaxies, but will not reach sufficient distances to sample all galaxy types. We can detect massive black holes in the center of many galaxies, but cannot probe very deeply.

Of even greater importance is a class of fundamental astrophysics, which we understand very poorly. Astronomy's greatest successes have been with processes involving relatively simple physics—for example gravity, which dominates the growth of structure in the universe, or equilibrium gas physics, which determines the structure of stars. However, several phenomena that are central to a complete understanding of the cosmos, including the formation of galaxies, stars, and planets, are governed by very messy nonequilibrium hydrodynamics. Only now is computer modeling becoming sufficiently powerful to attack these problems. It is, therefore, reasonable to expect that the theories of galaxy, star, and planet formation will advance rapidly in coming years.

Or they would advance rapidly, if observations existed to guide and test them. Unfortunately, these most theoretically difficult problems are, coincidentally, also among the most observationally difficult. Galaxy formation occurred long ago, and the observed systems are very small, faint, and distant. Star formation occurs deep within dense clouds of gas and dust, which are opaque to optical and even infrared radiation. Planetary systems are too small to resolve with present telescopes. It will take the next generation of ground and space telescopes in the optical, infrared, and radio to deal with these last big unsolved problems of astrophysics.

The infrared and radio telescopes are coming. The Atacama Large Millimeter Array (ALMA), an international project a few hundred miles north of Las Campanas, will provide access to those phenomena observable at radio wavelengths. The James Webb Space Telescope will do the same in the infrared. We very much hope the optical telescopes, behemoths of 20-meter-plus aperture, will quickly follow. The world's major observatories are busy planning for this next generation of giant telescopes. Carnegie is among them; we hope that the next Carnegie Year Book will describe our plans for a 20-meter telescope.

Among the most compelling programs for the future giant telescopes is the detection and observation of planetary systems around other stars. Recent work, particularly by Department of Terrestrial Magnetism Staff Member Paul Butler and his colleague (and former Carnegie Fellow) Geoff Marcy, has found evidence for many dozens of planets from the effects these planets have on the motions of their central star. However, there are not yet any direct observations of a planet beyond the solar system. The reason is simple: planets shine feebly by the reflected light of their star and, as seen from interstellar distances, are extremely close to the star. Thus, with current techniques their light is totally lost in the star's glare. However, new techniques of adaptive optics, which overcome the blurring effects of the atmosphere, combined with the much greater achievable resolution of the next generation of very large telescopes, give promise of directly observing planets, obtaining their images, and collecting their spectra. Spectroscopy—either from space or with giant ground-based telescopes—can determine a planet's composition and detect, among other things, signs of chemistry resulting only from living organisms. In all likelihood, the detection of life elsewhere in the universe is at most a few decades away.

It's an easy prediction that astronomy will look very different 40 years from now. I think there is a decent chance that Galileo and Hale's programs will be essentially complete. In the meantime, there is plenty to keep us busy.

—Augustus Oemler, Jr.
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Robert Kirschner, *Harvard University*
Jessica Krick, *University of Michigan*
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Howard Yee, *University of Toronto, Canada*
Ping Zhao, *Harvard University*

[1] To September 5, 2001
[2] From June 1, 2002
[3] From December 1, 2001
[4] From November 1, 2001
[5] From January 1, 2002
[6] From March 1, 2002
[7] To June 30, 2002
[8] From May 1, 2002
[9] To December 31, 2001
[10] To July 5, 2001
[11] From October 5, 2001
[12] From October 1, 2001
[13] To January 6, 2002
[14] To October 1, 2001

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THE DIRECTOR'S REPORT:

Worlds beyond the Ken of Mortal Eye

"ALTHOUGH WE ARE MERE SOJOURNERS ON THE SURFACE OF THE PLANET, CHAINED TO A MERE POINT IN SPACE, ENDURING BUT FOR A MOMENT IN TIME, THE HUMAN MIND IS NOT ONLY ENABLED TO NUMBER WORLDS BEYOND THE KEN OF MORTAL EYE, BUT TO TRACE THE EVENTS OF INDEFINITE AGES BEFORE THE CREATION OF OUR RACE."

*Sir Charles Lyell (1830)**

The lifetime of Charles Lyell, the great British geologist known best for championing the principle that the geological record is the product of processes visible at work on the modern Earth, spanned a remarkable period in the history of science that included the publication of Charles Darwin's *On the Origin of Species* and the discovery of the planet Neptune. At the end of the first volume of his landmark work, *Principles of Geology*, Lyell permitted himself a poetic exultation on the power of humankind's imagination to contemplate worlds and times vastly different from those directly known to us. Were he alive today, Lyell would no doubt nod with appreciation at the explosion of new information, all announced within the past seven and a half years, on planets orbiting stars other than our Sun. The discovery, characterization, and understanding of such extrasolar planets and the planetary systems they populate are topics occupying an increasing fraction of the attention of the members of our research staff in astronomy. One simple metric of the growth of the field is that a four-day conference, "Scientific Frontiers in Research on Extrasolar Planets," held at the Carnegie Institution's P Street facility in June, drew more than 200 papers.

The roots of astronomy at the Department of Terrestrial Magnetism (DTM) go back half a century, to 1952, when the department entered the then-new field of radio astronomy. At the urging of the Mount Wilson Observatory, DTM adapted for radio astronomical observations its expertise and antennae developed earlier for sounding the Earth's ionosphere. Another important step was taken two years later, when DTM director Merle Tuve was named chair of a committee appointed by Carnegie Institution president Vannevar Bush to exploit the rapidly developing technology of electronic imaging for astronomy. The efforts of that committee led to the development by several commercial manufacturers of prototypes of the image tube, and in 1957 Kent Ford was appointed to the DTM staff to lead the testing of those tubes and later the installation of the selected model at a number of astronomical observatories. The first

* C. Lyell, *Principles of Geology*, Vol. 1, Ch. 13 (1830).

Left: Jupiter, the largest giant planet in our solar system, serves as a model for giant planets around other stars. Extrasolar planet masses are commonly given in units of Jupiter masses, and models of extrasolar planetary atmospheres are based on those for Jupiter. From the distance of nearby stars, Jupiter is the first planet that would be detectable by methods now being used to search for extrasolar planets. This color mosaic of Jupiter was taken by the Cassini spacecraft in 2001, 17 days after closest approach while en route to Saturn; Jupiter's moon Io appears at left. (Courtesy NASA, Jet Propulsion Laboratory, University of Arizona.)

optical astronomer on the DTM staff was Vera Rubin, whom Tuve appointed in 1965 to guide the scientific application of image tube observations, and the Rubin-Ford work on the rotation curves of spiral galaxies and the clear evidence those observations provided for non-luminous matter was the most notable product of their long-term collaboration. When George Wetherill assumed the directorship of DTM in 1975 he brought an interest in solar system dynamics and planet formation, and within ten years the staff appointments of François Schweizer (1981), Alan Boss (1981), and John Graham (1985) added further expertise in galactic structure and evolution and star and planet formation.

That astronomy at DTM today is increasingly the astronomy of planetary systems is as much the result of an evolution in the membership of our research staff as it is the consequence of the promise of a new field of inquiry. The retirement of Ford in 1990, the move of Schweizer to the Carnegie Observatories in 1999, and the transitions to Senior Fellow, Director Emeritus, and Research Staff Member Emeritus by Rubin (2001), Wetherill (2002), and Graham (2002), respectively, created opportunities to add Staff Members with new interests. Paul Butler joined DTM in 1999, and Alycia Weinberger followed in 2001.

DTM's newest astronomer is Sara Seager (Fig. 1), who arrived in August 2002 after completion of graduate work at Harvard University and three years as a member of the Institute for Advanced Study. One of Seager's principal research areas, both prior to and since her arrival, is the modeling and characterization of the composition, structure, and dynamics of the atmospheres of giant extrasolar planets. An early focus has been on the so-called hot Jupiters or close-in extrasolar giant planets (CEGPs), which have orbital periods of several days and semi-major axes less than 0.1 AU (i.e., less than 10% of an Astronomical Unit, the distance between the Sun and the Earth). Because of their proximity to their central star, CEGPs are hot and potentially bright and should be good candidates for characterization by observations of the combined light of the planet-star system. Seager's models have provided a guide by which extrasolar planet observers have planned observational programs and interpreted their data. One noteworthy recent success of her modeling was her prediction that sodium might be detectable in the upper atmosphere of one particular CEGP, which in 1999 was discovered (by a group that included DTM's Paul Butler) to transit its star HD 209458 every 3.5 days. About one year ago, Hubble Space Telescope observations confirmed her prediction by documenting the absorption of transmitted starlight at a wavelength diagnostic of sodium.

Fig. 1. Sara Seager is DTM's newest Staff Member in astronomy.

During a transit by that planet (known as HD 209458 b), the light of its parent star dims by the ratio of planet-to-star areas, which has permitted a measurement of the planet's radius. The radius is an important quantity for assessing the planet's history, including the evolution of its atmosphere and its interior. Current theoretical models, however, predict values for the radius of this planet that disagree somewhat with observations. More

sophisticated models and observations of additional transiting planets are needed, both to resolve this discrepancy and more generally to understand the nature and history of planets in close proximity to their parent stars. With postdoctoral fellow Kaspar von Braun and colleague Gabriela Mallen-Ornelas (Harvard-Smithsonian Center for Astrophysics), Seager is leading a search for more transiting planets by monitoring tens to hundreds of thousands of stars simultaneously. Using several telescopes, including the Swope telescope at Carnegie's Las Campanas Observatory, she and her group will be searching field stars and open star clusters for the periodic decreases in brightness that signal short-period planets. In parallel with these observational efforts, Seager is extending her atmospheric models to extrasolar giant planets with a range of characteristics (Fig. 2).

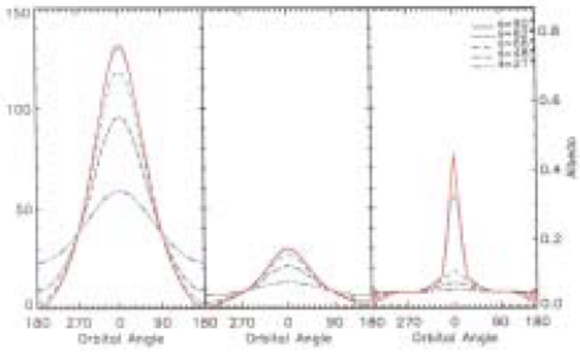

Fig. 2. Light curves for a short-period extrasolar giant planet are predicted by planetary atmosphere models of Sara Seager for different values of the orbital inclination (*i*), the angle between the plane of the planet's orbit and the line between the Earth and the star. As the planet orbits its parent star, it passes through different illumination phases as seen from Earth. The combined brightness of the star and planet will thus change during the planet's orbit, but by a very small amount (up to 130 parts per million). Planned spacecraft missions will be able to make measurements of a few parts per million that will permit the detection and study of perhaps hundreds of short-period giant planets. The precise shape of the light curve, shown for several models of the planet 51 Peg b (which has a four-day orbital period) with different assumptions regarding cloud particle type and size distribution, can tell us about the properties of the planet's atmosphere.

Seager's interests, in the longer term, include finding and characterizing extrasolar planets similar to Earth. She is developing a program to study theoretically all aspects of the spectral signatures of Earth-like extrasolar planets as well as the variability in those signatures. Although the detection of Earth analogs will likely not occur for a number of years, model results are important for designing space missions aimed at discovering and characterizing such objects. Seager serves on a working group now setting the scientific requirements for NASA's Terrestrial Planet Finder mission, slated for launch in the middle of the next decade.

Paul Butler continues his search, carried out in collaboration with colleagues from the University of California, for new extrasolar planets. Using a technique that he developed, Butler and his team have been making careful measurement of time-dependent shifts in the spectra of nearby bright stars indicative of motion of the star along the line of sight from the Earth. Periodic signals clearly above the noise level (currently about 3 m/s radial velocity) may indicate that a star harbors one or more planets. In the past year, Butler's group has announced confirmed detections of about 30 new extrasolar planets, including evidence for multiple planet systems around four stars (bringing the total set of well-documented multiple extrasolar planetary systems to eight). One of these planetary systems, that of the star 55 Cancri, includes the first planet known to be in an orbit about as distant from its star as Jupiter is from the Sun (Fig. 3). The discovery of further Jupiter analogs, comparable to Jupiter in both mass and stellar distance (i.e., having an orbital period near 12 years), will be important in understanding the extent to which our solar system is typical of the general population of planetary systems.

More than 100 extrasolar planets are now known. The distribution by mass (Fig. 4) increases rapidly with decreasing mass below about 8 Jupiter masses and continues to rise all the way to the present detection limit. Above 8 Jupiter masses, in contrast, the mass distribution is flat. The shape of this distribution constrains discussions of the distinction—increasingly difficult to make on observational grounds—between large planets, formed from circumstellar disks, and low-mass

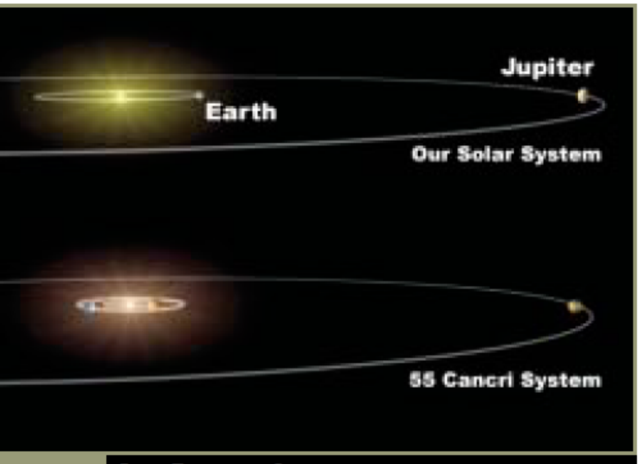

Fig. 3. The star 55 Cancri features one of eight known examples of a multiple extrasolar planetary system. The outermost planet, recently discovered by Paul Butler and his colleagues, is the nearest known analog to Jupiter in terms of mass and stellar distance (or orbital period). (Courtesy Jet Propulsion Laboratory.)

(brown dwarf) stellar companions, formed together with the primary star by collapse of a molecular cloud core.

Butler and his team have targeted 2,000 of the nearest stars for long-term observations, including chromospherically quiet main-sequence stars from late F class through early K class out to a distance of 50 parsecs, later K stars to 30 parsecs, and M dwarfs to 10 parsecs. Surveys of northern hemisphere stars are well underway at the Lick 3-m and Keck 10-m telescopes, and surveys of the brightest 250 southern hemisphere stars are being made at the 3.9-m Anglo-Australian Telescope. Butler, postdoctoral associate Christopher McCarthy, and their collaborators last year initiated a survey of fainter southern hemisphere stars with the Magellan 6.5-m telescopes at the Las Campanas Observatory.

Alycia Weinberger continues her study of circumstellar disks around young stars. With the goal of expanding the inventory of known disk systems at different evolutionary stages, she first makes high-resolution spectroscopic observations to identify young stars within 100 parsecs. The strength of spectral lines of key species can provide age indicators, and radial velocities obtained from spectral shifts can confirm dynamical association of groups of stars believed to have formed from the same parent cloud under similar initial conditions. She then obtains mid-infrared images of young stars either with the Magellan telescopes or at the Keck Observatory. Those with infrared emission in excess of the level expected from the stellar photosphere are candidates for hosting hot, close-in circumstellar dust and are targeted for further study.

During the past year Weinberger, together with collaborators at UCLA, reported the first spatially resolved spectroscopy of the 12-million-year-old star β Pictoris (the first star for which a circumstellar disk was imaged). She and her coworkers showed that dust very close to the star displays emission features diagnostic of silicates, including amorphous and crystalline species, although farther from the star no emission features are resolvable. That the shape of the silicate peak does not change significantly over the stellar distances where it can be seen implies that the relative abundances of amorphous and crystalline grains remain

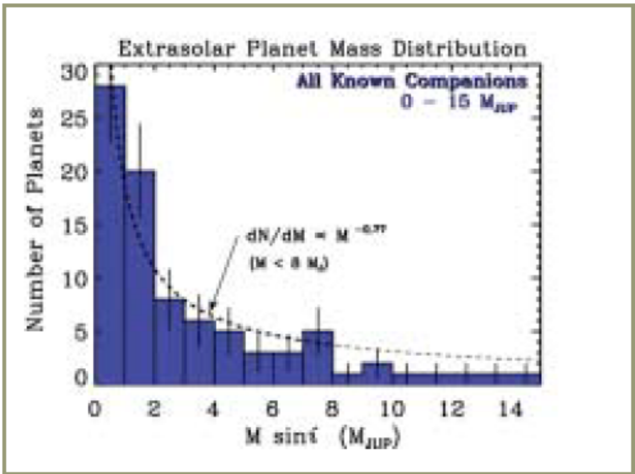

Fig. 4. A histogram of extrasolar planets by mass, compiled by Paul Butler and his collaborators, illustrates important general aspects of planetary formational processes. The horizontal axis is not true planet mass, but rather the product of mass (in units of Jupiter masses) and the sine of the inclination (*i*) of the planetary orbit to the Earth-star line. For only one extrasolar planet (HD 209458 b) is the inclination known independently (from transit observations). The distribution follows an inverse power law below 8 Jupiter masses.

approximately constant with radial distance. The lack of emission features farther from the star could mean that silicate grains are coated with ices in the colder portions of the disk.

From mid-infrared images of the β Pictoris disk at a resolution of 10 AU, Weinberger and her collaborators have detected a pronounced warp in the disk inward of 20 AU from the star (Fig. 5). This warp is at a different orientation than a shallower and larger-scale warp previously observed at visible wavelengths with the Hubble Space Telescope. One possible explanation for the inner warp is a giant planet in an orbit that is tilted with respect to the median plane of the circumstellar dust. Current theories for giant planet formation, such as those of Alan Boss, predict that β Pictoris is sufficiently old for Jupiter-mass planets to have formed.

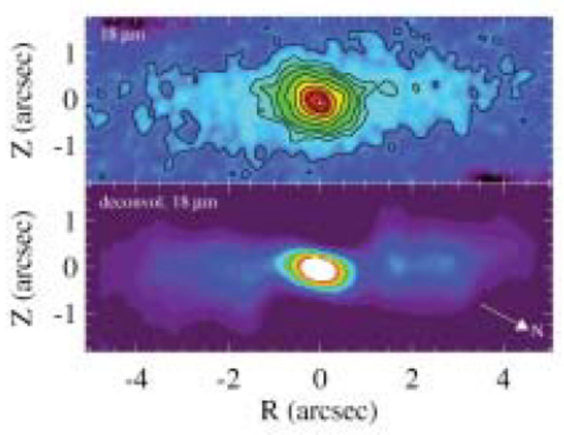

Fig. 5. Mid-infrared imaging of the young star β Pictoris by Alycia Weinberger and colleagues reveals spatial asymmetries in its dusty circumstellar disk. Visible for the first time is an inner (within about 1″ of arc, or 20 AU, of the star) warp in the disk (tilting at about 15° from upper left to lower right) that is aligned differently from a larger-scale warp seen in scattered light by the Hubble Space Telescope. At the top is a false-color image, at a wavelength of about 18 µm, of dust heated by the star to temperatures of 150-500 K; the bottom version of the image incorporates a deconvolution procedure to sharpen resolution.

The conventional view of solar system formation is that a presolar molecular cloud core collapsed in a region of low-mass star formation, similar to Taurus-Auriga. In such a quiescent setting, the background ultraviolet (UV) flux is likely to be low and limited largely to the flux from the early Sun. Alan Boss, together with George Wetherill and postdoctoral associate Nader Haghighipour, recently proposed a new scenario for solar system formation that challenges this conventional view. Boss's scenario is based on forming the solar system in a region of high-mass star formation, similar to the Orion Nebula cluster, and relies on a high flux of UV radiation from nearby massive stars to remove the gaseous portion of the solar nebula from Saturn's orbit and beyond. Gas-giant protoplanets formed from instabilities in the circumstellar disk (Fig. 6) by this hypothesis, and the high UV flux served to strip the gaseous envelopes from the outermost gaseous protoplanets by photoevaporation, leaving cores consisting dominantly of ice and rock that evolved to become the ice-giant planets, Uranus and Neptune.

Terrestrial planet formation was likely to have proceeded largely unimpeded and may even have been somewhat hastened by the gravitational perturbations from a rapidly formed Jupiter, according to simulations by George Wetherill and coworkers. Because the inner solar system is deep within the Sun's gravitational potential well, Boss argues, a halo of hydrogen gas would have been retained inside 10 AU and would have protected the planetesimals and gases of the inner solar nebula. Planetesimals and cometesimals outside this distance, in contrast, would have been subject to a withering UV flux once the disk gas in their vicinity was photoevaporated. UV photons should have led to photolysis of the ices on the surfaces of these bodies, however, producing polycyclic aromatic hydrocarbons and amino acids; i.e., a thick layer of organic compounds that formed an effective sun block. Beneath this surface layer, the pristine nature of these bodies would have been retained. Boss's scenario thus suggests that prebiotic UV-driven chemistry would have been vigorous in the outer regions of the solar nebula even as the planetary accumulation process was under way.

If this scenario describes the origin of the solar system, then it may have more general applicability to other planetary systems. Most stars are believed

to have formed in regions of high-mass star formation, with perhaps only a minor fraction forming in regions similar to Taurus-Auriga. If the solar system formed in a region similar to Orion, then the prospects for finding and characterizing other Earth-like planets increase severalfold. Future space missions such as Kepler, for which Boss is a member of the science team, are designed with the aim of determining the frequency of Earth-like planets and can serve to test whether this conjecture is correct.

What is already clear from the exciting findings of the past seven and a half years is that planets and planetary systems are common outcomes of star formation. We have barely begun to characterize those planets, all of which detected to date are gas giants and all but one of which are closer to their

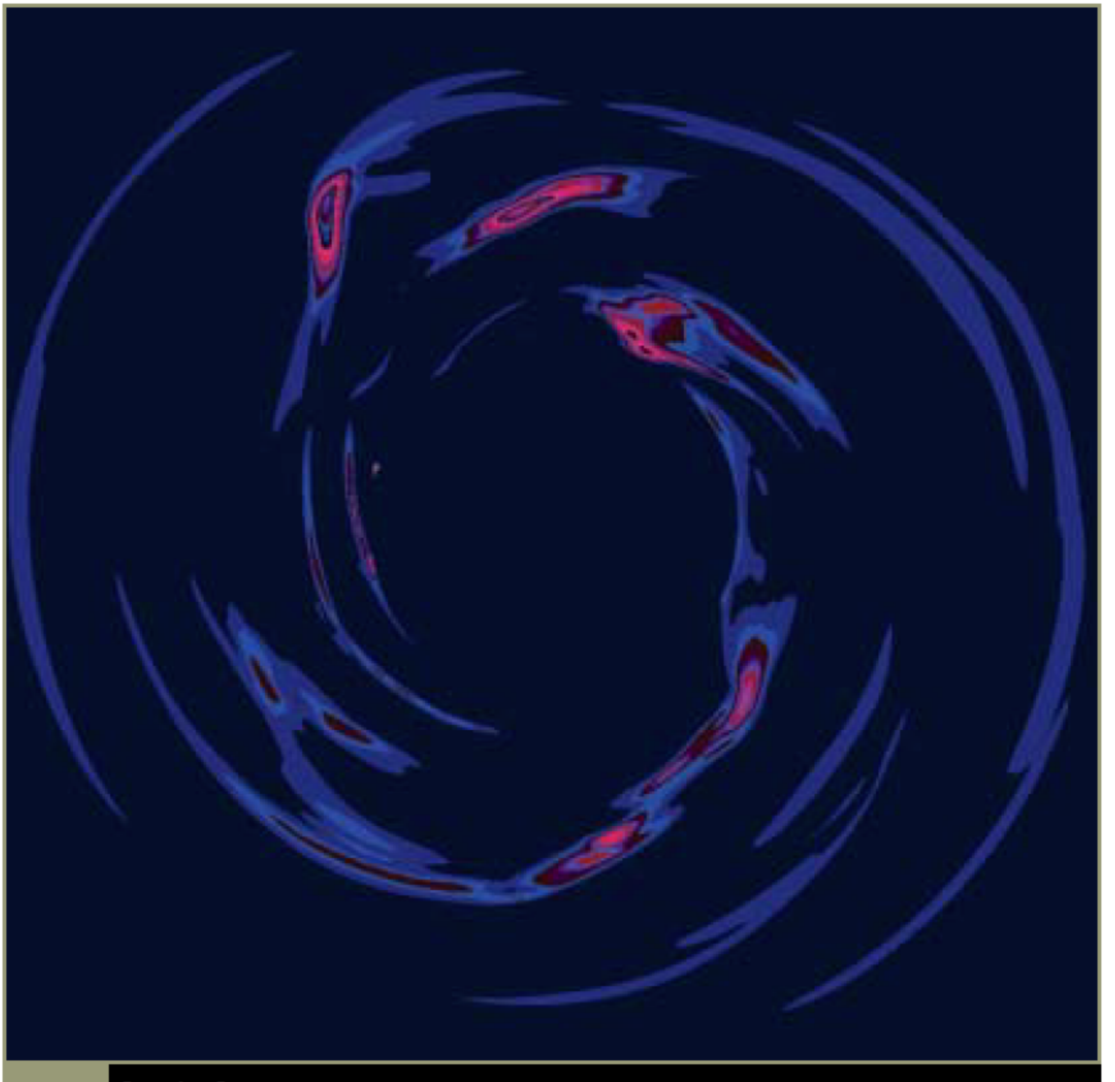

Fig. 6. Alan Boss has shown with theoretical models that giant planets can form rapidly from instabilities in a circumstellar disk. Depicted are equatorial density contours for one such three-dimensional, radiative hydrodynamics calculation of disk instability. The region shown is 30 AU in radius, with an inner region of radius 10 AU excised. A number of well-defined clumps (regions shown in red) have formed after 340 years.

Fig. 7. Members of the Department of Terrestrial Magnetism staff are shown on November 6, 2002. First row (from left): Jaime Sosa, Pedro Roa, Ambre Luguet, Pablo Esparza, Fouad Tera, Aki Roberge, Kathleen Flint, Brian Schleigh, George Wetherill. Second row: Janice Dunlap, Mary Horan, Daniela Power, Steven Desch, Timothy Mock, Petrus le Roux, Mark Behn, Peter Burkett, Richard Carlson, Derek Schutt, Mark Schmitz, David James, Louis Brown, Selwyn Sacks, Steve Shirey, Nelson McWhorter. Third row: Eugenio Rivera, Nader Haghighipour, Terry Stahl, Ben Pandit, Erik Hauri, Shaun Hardy, Michael Acierno, Myung Gyoon Lee, Alycia Weinberger, Mary Coder, Roy Scalco, Bill Key. Fourth row: Roy Dingus, Georg Bartels, Conel Alexander, Jay Bartlett, Gary Bors, Paul Butler, Kevin Burke, John Graham, Steven Hauck, Sean Solomon, Brooke Hunter, Vera Rubin.

star than the giant planets of our solar system are to the Sun. While analogs to our solar system and to the Earth have yet to be discovered, intensive plans are underway to carry out searches capable of finding them. Like Lyell, we live in a remarkable era, but it is one in which an increasing number of worlds are not only well within “the ken of mortal eye” but also within our ability to formulate and test specific hypotheses for their formation and evolution.

—Sean C. Solomon

Department of Terrestrial Magnetism Personnel

July 1, 2001 – June 30, 2002

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[1] From March 31, 2002
[2] From August 5, 2002
[3] From August 1, 2001
[4] Joint appointment with GL
[5] From December 17, 2001
[6] From September 1, 2001
[7] From July 2, 2001
[8] To April 30, 2002
[9] To March 31, 2002
[10] To October 15, 2001
[11] From November 5, 2001
[12] To December 31, 2001
[13] From March 1, 2002
[14] From December 3, 2001
[15] To October 20, 2001
[16] From September 4, 2001
[17] To June 30, 2002

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THE DIRECTOR'S REPORT:

On the Horizon

On July 1, 2002, Carnegie officially launched its sixth scientific department, Global Ecology. The emergence of the global ecology concept has been a great adventure, with tremendous support from the scientific community, the institution, and the trustees. Now, we are starting the transition from concept to reality. As we add definition and infrastructure to the vision, we face both opportunities and challenges. From my perspective, Andrew Carnegie's bold strategy when founding the institution provides a philosophy for capitalizing on the opportunities and managing the challenges.

The history of the Department of Global Ecology has a long and a short version. The long version begins with the founding of the institution over a century ago. Investigators in the departments of Botany, Marine Biology, Genetics, and even Terrestrial Magnetism explored interactions between the biological and physical worlds. Many of the discoveries, as well as the unanswered questions of Carnegie scientists, built the foundations for the new department. The short history begins with the planning for the institution's centennial, which provided a stimulus to think big, to review the past, and to make new investments in the future.

In May 2001, the trustees decided that the new Department of Global Ecology was the right option for the institution. It would build on past accomplishments and present resources, and it would address the kinds of preeminent scientific and societal challenges mandated by Andrew Carnegie's 1902 Trust Deed.

What is global ecology?

Global ecology is a new discipline aimed at understanding the integrated function of the Earth's ecosystems, including living organisms and their interactions with the land, the oceans, the atmosphere, and human activities. The field focuses on ecosystem structure and function across a wide range of spatial scales. It is especially concerned with new and altered phenomena that emerge as the boundaries of a study system grow. Effects of some mechanisms, such as carbon fixation through photosynthesis, penetrate almost seamlessly across spatial scales from biochemistry to global element cycles. Other mechanisms, such as impacts of ecosystems on climate, depend on interactions that become important only over large areas.

Global ecology integrates perspectives and technologies from many disciplines. Ecologists need to work with specialists in molecular biology, oceanography, atmospheric science, geology, hydrology, and soil science, as well as with social scientists. A group the size of a Carnegie department cannot hope for comprehensive coverage of these disciplines. But, we can capitalize on our unique set of interests and resources. Our approach starts from basic biology, with the goal of assembling a team of scientists that has a deep understanding of the function of individual organisms, and a dedication to explore the implications of and controls on organism function at the global scale.

Other institutions studying the global environment are taking a range of approaches, with a variety of different names. Programs emphasizing

Left: The field of global ecology focuses on ecosystem structure and function across a wide range of spatial scales—from the microscopic to the entire planet. (Courtesy NASA.)

physical sciences, human dimensions, biogeochemistry, and energy and resources all represent important efforts to connect the necessary skills and perspectives. This diversity of approaches is a strength, pushing at the limits of knowledge from many directions and providing a range of partnership opportunities.

Big questions

Ours is an era of profound discoveries about the structure and function of individual organisms and about the function of integrated systems. As we unlock the genetics of minute marine plankton, we are also beginning to understand the role of wind-borne dust in controlling their distribution and abundance. As we develop new crop varieties with the potential to feed billions, we are also starting to appreciate how poor management of fertilizers can alter climate, perhaps negating the gains from the new varieties. Almost everywhere we look, large-scale, long-term interactions have the potential to dominate the structure and function of the natural world.

Global Ecology will address a broad range of basic questions. Some concern the organization of the Earth's ecosystems. For example, why is the distribution of the major ecosystem types so consistently related to climate? Or, what is the nature of the relationship between biological diversity and ecosystem function? Others concern interactions between the Earth's biological and physical systems. For example, what is the role of vegetation in modulating climate? Or, how do changes in terrestrial vegetation influence the transport of nutrient-rich dust from land to ocean ecosystems? These questions probe deeply into the structure and function of the natural world. Some of these questions are not new. For example, a 1902 Carnegie committee charged the then-new Department of Botany with understanding the role of vegetation in controlling climate. Most of these big questions are not yet answered. Only now are the available tools becoming powerful enough to provide definitive answers.

Global Ecology can also provide critical foundations for understanding and solving applied problems. Human actions are already so pervasive and intense that they have major impacts on the Earth's physical and biological systems. We are, in essence, engaging in a series of vast, unreplicated experiments, with the planet as the experimental system. Some of these experiments may make the Earth more productive or sustainable. Others may lead to massive social and/or economic costs. Understanding the ecological and physical mechanisms that underlie the impacts will have tremendous value for the dialogue on strategies for facilitating beneficial changes, preventing detrimental ones, and adapting to the changes that cannot be prevented. Contributing to the scientific foundation for a sustainable future is a core motivation for Global Ecology.

Tools and approaches

Until recently, large-scale studies of ecosystems and interactions between the biological, physical, and cultural worlds were exceedingly difficult. We lacked the tools for quantifying large-scale ecological processes and for integrating information from diverse branches of science. Recently, however, the pace of technological and conceptual innovation has been almost dizzying. Just as the development of molecular techniques has powered an explosion of basic biological knowledge, the development of new satellite sensors, computer models, and global informatics resources is beginning to fuel a parallel explosion in understanding the Earth's ecosystems. In the future, creative approaches for synthesizing and interpreting vast quantities of data will be as important as new instruments and data-collection systems.

The key tools need to address a continuum of spatial scales. Remote-sensing instrumentation, especially on satellites, and atmospheric transport models increasingly allow researchers to map the planet and quantify its metabolic activity. At the other end of the spatial scale, molecular tools that assess phylogenies, infer the composition of microbial communities, and explore the expression

of entire genomes are opening a new level of access to the ways individuals function in ecosystems. And a whole new class of informatics resources makes it increasingly practical to link and explore the large, multifactor datasets that characterize global ecology problems.

Conceptual advances will be as important as technical ones. Many of the conceptual advances concern the growing appreciation and understanding of the "connectedness" among biological and physical components of Earth. It is increasingly clear, for instance, that the transport of dust from land to the oceans exerts a major control on ocean photosynthesis through the delivery of iron, an essential nutrient for marine organisms. Thus, understanding photosynthesis in the oceans requires knowledge about the climate, vegetation, and human processes that produce dust on land. Ocean photosynthesis is also a potentially major controller of climate through the transfer of the greenhouse gas carbon dioxide from the atmosphere to the oceans. Studies on any part of this interconnected system could uncover a range of important mechanisms, but to understand the overall function, we must learn how all the components interact.

Faculty

Global Ecology opens for business with a faculty of three. We have diverse skills and approaches but a shared dedication to understanding ecosystems at the global scale. Joe Berry, a faculty member at Plant Biology since 1972, began his career at Carnegie focusing on the biochemistry of photosynthesis and understanding the interplay between the biochemistry and environmental factors. Joe's studies at the leaf and biochemical levels led to an appreciation of the role of photosynthesis in regulating the composition of the atmosphere, especially the isotopes of carbon and oxygen. Beginning in the mid-1980s, this interest led Joe to become one of the first plant biologists to work closely with climate scientists. This work led to groundbreaking efforts at representing plant processes in climate models, which have paid dividends in our understanding of climate and plant growth. Recently, Joe's research has shifted to a set of key challenges at three important scales. At the global scale, he continues to pioneer methods for interpreting plant processes through studies of the atmosphere. At scales of hundreds to thousands of square kilometers, his group is developing methods to estimate fluxes of carbon dioxide and carbon isotopes, building on links to atmospheric water transport. And at a scale that is both holistic and compact, Joe has taken a lead in using Biosphere 2, a large, enclosed set of synthetic ecosystems, to test hypotheses about ecosystem process ranging from isotope fractionation to responses of the rain forest to changing atmospheric composition. A true innovator, Joe is one of the intellectual founders of the field of global ecology and an appropriate founding member of the Carnegie department.

Greg Asner joined Carnegie as a faculty member in 2001. He is one of the first professional practitioners in global ecology, armed with specific training in interdisciplinary approaches and large-scale analysis. A leader in remote-sensing data analysis, Greg has specialized in two areas. One is interpretation of ecosystem processes, especially nutrient cycling, from satellite data. The other involves changes in woody vegetation. In semiarid ecosystems, Greg looks at the causes, extent, and implications of increases in woody vegetation, which is widespread in North America, South America, and Africa. In tropical rain forests, especially in Brazil, Greg and his group are using aircraft and satellite data to quantify and understand the impacts of low-intensity logging, a phenomenon that is pervasive but difficult to observe with traditional techniques. Combining unusual skills at both the fieldwork and integrative ends of global ecology, Greg is a model for where the field is headed.

I joined the Department of Plant Biology in 1984 with an interest in integration across scales. In the mid-80s this interest focused on extrapolating data from the leaf to the whole plant. After years of searching for scaling relationships at the plant

scale, I realized that there should be similar relationships at ecosystem and global scales. Searching for these relationships and testing their generality has led me to diverse problems in global ecology, ranging from estimates of global plant growth on the land and oceans to how ecosystems respond to global change.

Future faculty growth at Global Ecology will be targeted at areas that are scientifically rich, complementary to existing skills, and poised for major breakthroughs. Our next appointment, sometime in 2003, will be a biological oceanographer, a position that was made possible through a major grant from the Gordon and Betty Moore Foundation. We are especially interested in a person who uses molecular tools to link biological diversity and microbial community composition with large-scale fluxes of carbon and other elements. Such a scientist could help the department make major contributions to our understanding of the integration of biological, chemical, and physical processes in the oceans, as well as the integration of ocean and land processes.

Further appointments are still under discussion. Possible specialties include atmosphere/biosphere interactions; the function and genetic diversity of soil microbial communities; the large-scale organization of the biosphere; and the global food production system.

Scientific agenda

The scientific agenda for Global Ecology is remarkably complete in the institution's 1902 Trust Deed from Andrew Carnegie as excerpted below:

- …in the broadest and most liberal manner encourage investigation, research and discovery…
- …show the application of knowledge to the improvement of mankind…
- …discover the exceptional man [or woman] in every department of study and enable him to make the work for which he seems specially designed, his life's work.

We expect to fulfill our mission with three complementary approaches. First, we will continue the integrative, innovative science that has been the hallmark of the institution and that has brought the current faculty to Global Ecology. Second, we want to establish new links between disciplines and perspectives. Collaborations with molecular biologists at Plant Biology, astrobiologists at the Geophysical Lab, and the natural scientists, social scientists, and engineers at Stanford University are particularly promising. Third, we want to develop integrated programs that build on the interests of the Global Ecology faculty. We are very excited about an airborne observatory—the global ecology version of a major astronomical telescope and an area where Carnegie has a rich history. A set of aircraft-mounted instruments could give us the capability to test and develop new technologies for space deployment, to conduct regional studies with a variety of remote-sensing techniques, and to monitor global changes over extended periods.

Departmental home

The new department will need new quarters. After exploring many possibilities, we decided that the best home for Global Ecology was on the Plant Biology campus, located on seven acres leased from Stanford University. This location encourages collaborations with faculty at Plant Biology and Stanford, and it facilitates our continued involvement in graduate and undergraduate teaching. It also allows us to share facilities and administration with Plant Biology.

The new space will include an approximately 11,000-square-foot research building, 4,000 square feet of research greenhouses, and a 3,000-square-foot space for staging, storage, and equipment development. Our design places a high priority on minimizing environmental impacts while maximizing occupant comfort and health.
This project strives for minimal environmental footprints, for three reasons. First, researchers dedicated to understanding the foundations for a sustainable future have special opportunities to contribute to sustainability through creative

design. Second, an energy-efficient and cost-efficient home will make the Carnegie resources go further. Third, this project serves as an example, encouraging other parts of the community to look seriously at "green" buildings. We are especially pleased that the David and Lucile Packard Foundation joined the institution as a major supporter of the green laboratory concept.

Some of our motivations for emphasizing a green design are purely practical, and others are largely philosophical. Our goal in selecting specific features is to make the practical and philosophical considerations work together. It is important that the buildings make the statement that it is not necessary to sacrifice economy, comfort, worker efficiency, or beauty for low environmental impact.

—Christopher Field

Extradepartmental and Administrative

Carnegie Administrative Personnel

Lloyd Allen, *Building Maintenance Specialist*
Sharon Bassin, *Assistant to the President/Assistant Secretary to the Board*
Sherrill Berger, *Research Assistant, External Affairs*
Andrea Bremer, *Business Coordinator*
Gloria Brienza, *Budget and Management Analysis Manager*
Don A. Brooks, *Building Maintenance Specialist*
Marjorie Burger, *Financial Accountant*[1]
Cady Canapp, *Human Resources and Insurance Manager*
Ellen Carpenter, *Public Events and Publications Coordinator*
Karin Dasuki, *Financial Accountant*[2]
Sonja DeCarlo, *Business Officer*
Linda Feinberg, *Manager of External Affairs*
Charles Fonville, *Lobby Attendant*[3]
Susanne Garvey, *Director of External Affairs*
Claire Hardy, *Database and Communications Coordinator*
Margaret Hazen, *Staff Director, Centennial Committee*
Susan Humphreys, *Secretary to the President*[4]
Darla Keefer, *Administrative Secretary*
Ann Keyes, *Payroll Coordinator*
Charles Kim, *Systems Administrator*
Jeffrey Lightfield, *Deputy to the Financial Manager*[5]
John Lively, *Director of Administration and Finance*
Tina McDowell, *Editor and Publications Officer*
Trong Nguyen, *Financial Accountant*
Michael Pimenov, *Endowment Manager*
Arnold Pryor, *Facilities Coordinator for the Centennial*
Paul Ruther, *Centennial Researcher*[6]
Maxine F. Singer, *President*
John Strom, *Web Manager*
Kris Sundback, *Financial Manager*
Vickie Tucker, *Administrative Coordinator/Accounts Payable*
Yulonda White, *Human Resources and Insurance Records Coordinator*
Jacqueline Williams, *Assistant to Manager, Human Resources and Insurance*

[1] From April 1, 2002
[2] To October 5, 2001
[3] From October 15, 2001
[4] To August 8, 2002
[5] From November 5, 2001
[6] To December 31, 2001

Carnegie Academy for Science Education

Dayo Akinsheye, *Mentor Teacher*[1,2]
Addae Akinsheye, *Intern*[2]
Sarah Bax, *Mentor Teacher*[1,2]
Keith Butler, *Technology Consultant*[1]
Inés Cifuentes, *CASE Director*[1,2]
Barbara Clements, *Mentor Teacher*[1]
Asonja Dorsey, *Mentor Teacher*[1,2]
Julie Edmonds, *CASE Associate Director*[1,2]
Fran Ewart, *Mentor Teacher*[1]
Emily Feinberg, *Intern*[2]
Edwin Gasaway, *Intern*[2]
Vanessa Gonzales, *Intern*[2]
Jacqueline Goodloe, *Mentor Teacher*[1]
Toby May Horn, *DCACTS Coordinator*[1,2]
Charles James, *CASE Science Coordinator*[1,2]
Corey Khan, *Intern*[1]
Brian LaMacchia, *Mentor Teacher*[1,2]
Asha Mathur, *Mentor Teacher*[1,2]
Fran McCrackin, *Mentor Teacher*[1,2]
Kelliston McDowell, *Intern*[1,2]
Sharon Musa, *Mentor Teacher*[1,2]
Thomas Nassif, *Mentor Teacher*[1,2]
Monica Negoye, *Consultant, Mathematics Institute*[1]
Shirley Payne, *Mentor Teacher*[2]
Emily Raskin, *Mentor Teacher*[2]
Tiffany Rolling, *First Light Assistant*[1,2]
Christine Sills, *Mentor Teacher*[1]
Subashni Singh, *Intern*[1]
Carol Sovine, *Mentor Teacher*[1,2]
Gregory Taylor, *CASE Technology Coordinator, First Light Lead Teacher*[1,2]
Lindsey Taylor, *Intern*[1]
Annie Thompson, *Mentor Teacher*[2]
Sue P. White, *CASE Mathematics Coordinator*[1,2]
Latisha Whitley, *Intern*[1,2]
Laurie Young, *Mentor Teacher*[2]

[1] Summer Institute 2001
[2] Summer Institute 2002

Publications of the President

Singer, Maxine F., "The Challenge to Science: How to Mobilize American Ingenuity," in *The Age of Terror: America and the World after September 11*, Basic Books, New York, 2001.

Singer, Maxine F., "Scientific and Medical Aspects of Human Reproductive Cloning," newsletter of the American Society for Biochemistry and Molecular Biology, April 2002.

The Capital Science Lectures are sponsored by the Carnegie Institution with substantial support from Human Genome Sciences, Inc., and the Johnson & Johnson Family of Companies. The lectures—free and open to the public—are held in the Root Auditorium at Carnegie's headquarters at 16th and P Streets in Washington, D.C. Speakers also meet informally with groups of high school students. During the 2001-2002 year, the following lectures were given:

CAPITAL SCIENCE LECTURES AND OTHER EVENTS—CENTENNIAL SEASON 2001-2002

Cryptography, Trust, Privacy, and Adversity, Michael O. Rabin (Division of Engineering and Applied Science, Harvard University) October 23, 2001.

The Origins of Evolution, Jack W. Szostak (Investigator, Howard Hughes Medical Institute; Professor of Genetics, Harvard Medical School; Alex Rich Distinguished Investigator, Massachusetts General Hospital), November 27, 2001.

Deciphering the "Switches": How Genes Are Expressed and Repressed, Jasper Rine (Department of Molecular and Cellular Biology, University of California, Berkeley) December 11, 2001.

Promises and Realities of Tissue Engineering, Linda G. Griffith (Department of Chemical Engineering and Division of Bioengineering and Environmental Health, Massachusetts Institute of Technology) January 15, 2002.

NOVA'S "The Diamond Deception," Robert Hazen (Staff Scientist, Geophysical Laboratory, Carnegie Institution of Washington) January 29, 2002.

Navigating Uncharted Waters: Humans and Oceans Today, Jane Lubchenco (Distinguished Professor of Zoology and Wayne and Gladys Valley Professor of Marine Biology, Oregon State University) February 5, 2002.

NOVA'S "Venus Unveiled," Sean C. Solomon (Director, Department of Terrestrial Magnetism, Carnegie Institution of Washington) February 26, 2002.

NOVA'S "Runaway Universe," Wendy Freedman (Staff Scientist, The Carnegie Observatories, Carnegie Institution of Washington) March 5, 2002.

Mad Cows and "Psi-Chotic" Yeast: Revolutionary New Views in Human Disease and Genetics, Susan Lindquist (Investigator, Howard Hughes Medical Institute; Professor of Medical Sciences, University of Chicago) March 12, 2002.

The Accelerating Universe, Robert P. Kirshner (Clowes Professor of Science, Harvard University) March 19, 2002.

NOVA/Frontline's "Harvest of Fear," Christopher Somerville (Director, Department of Plant Biology, Carnegie Institution of Washington) April 2, 2002.

Sexual Signaling on a Cellular Level: Lessons from Plant Reproduction, Daphne Preuss (Professor of Molecular Genetics and Cell Biology, University of Chicago; Assistant Investigator, Howard Hughes Medical Institute) April 9, 2002.

Words and Rules: The Ingredients of Language, Steven Pinker (Professor of Psychology, Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology) May 7, 2002.

NOVA's "Cracking the Code of Life," Maxine F. Singer (President, Carnegie Institution of Washington) May 21, 2002.

Financial Statements
for the year ended June 30, 2002

Financial Profile

Reader's Note: In this section, any discussion of spending levels or endowment amounts are on a cash or cash-equivalent basis. Therefore, the funding amounts presented do not reflect the impact of capitalization, depreciation, or other non-cash items.

The primary source of support for Carnegie Institution of Washington's activities continues to be its endowment. This reliance has led to an important degree of independence in the research program of the institution. This independence is anticipated to continue as a mainstay of Carnegie's approach to science in the future.

At June 30, 2002, the endowment was valued at approximately $501.8 million and had a total return (net of management fees) of 3.1%. The annualized five-year return for the endowment was 10.3%.

For a number of years, Carnegie's endowment has been allocated among a broad spectrum of asset classes. This includes fixed-income instruments (bonds), equities (stocks), absolute return investments, real estate partnerships, private equity, an oil and gas partnership and a hedge fund. The goal of diversifying the endowment into alternative assets is to reduce the volatility inherent in an undiversified portfolio while generating attractive overall performance.

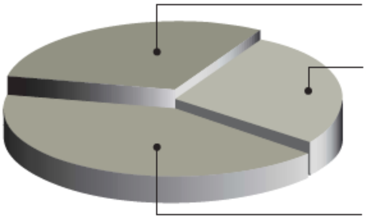
In its private equity allocation, the institution accepts a higher level of risk in exchange for a higher expected return. By entering into real estate partnerships, the institution in effect, holds part of its endowment in high quality commercial real estate, deriving both the possibility of capital appreciation and income in the form of rent from tenants. Along with the oil and gas partnership, this asset class provides an effective hedge against inflation. Finally, through its investments in an absolute return partnership and a hedge fund, the institution seeks to achieve long-term returns similar to those of traditional U.S. equities with reduced volatility and risk.

The finance committee of the board regularly examines the asset allocation of the endowment and readjusts the allocation, as appropriate. The institution relies upon external managers and partnerships to conduct the investment activities, and it employs a commercial bank to maintain custody.

The following chart shows the allocation of the institution's endowment among the asset classes it uses as of June 30, 2002:

	Target Allocation	Actual Allocation
Common Stock	32.5%	32.1%
Alternative Assets	42.5%	41.4%
Fixed Income and Cash	25.0%	26.5%

Actual Asset Allocation



Carnegie's investment goals are to provide high levels of current support to the institution and to maintain the long-term spending power of its endowment. To achieve this objective, it employs a budgeting methodology that provides for:

- averaging the total market value of the endowment for the three most recent fiscal years, and

- developing a budget that spends at a set percentage (spending rate) of this three-year market average.

Since the early 1990s, this budgeted spending rate has been declining in a phased reduction, moving towards an informal goal of a spending rate of 4.5%. For the 2001-2002 fiscal year, the rate was budgeted at 5.25%. While Carnegie has been

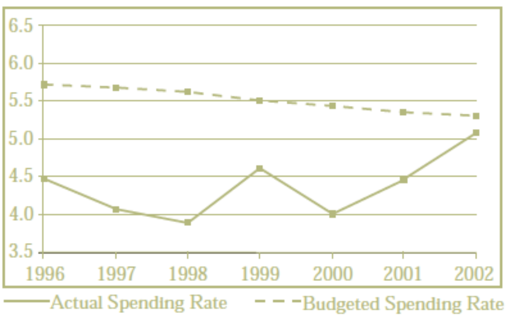
Carnegie Funds Spending Over Seven Years

(Dollars in Millions)

FY	95-96	96-97
Carnegie Funds Spending	$ 15.1	$ 15.5
Actual Market Value at June 30	$338.0	$382.9
Actual Spending as % of Market Value	4.48%	4.05%
Planned Spending Rate in Budget	5.71%	5.66%

reducing this budgeted rate by between 5 and 10 basis points a year, there has also been continuing, significant growth in the size of the endowment, until the most recently ended fiscal year. The result has been that, for the 2001-2002 fiscal year, the actual spending rate (the ratio of annual spending from the endowment to actual endowment value at the conclusion of the fiscal year in which the spending took place) was 5.07%.

Budget and Actual Spending Rates



The table below compares the planned versus the actual spending rates, as well as the market value of the endowment from 1995-1996 to the most recently concluded fiscal year, 2001-2002.

Within Carnegie's endowment, there are a number of "Funds" that provide support either in a general way or in a targeted way, with a specific, defined purpose. The largest of these is the Andrew Carnegie Fund, begun with the original gift of $10 million. Mr. Carnegie later made additional gifts totaling another $12 million during his lifetime. Together these gifts are now valued at over $408 million.

97-98	98-99	99-00	00-01	01-02
$ 16.4	$ 20.9	$ 20.0	$ 22.8	$ 25.5
$423.3	$451.6	$477.9	$512.0	$501.8
3.87%	4.63%	4.18%	4.45%	5.07%
5.61%	5.50%	5.40%	5.30%	5.25%

UNAUDITED

The following table shows the amount in the principal funds within the institution's endowment as of June, 2002.

Market value of the Principal Funds Within Carnegie's Endowment

Andrew Carnegie	$408,787,970
Capital Campaign	34,759,974
Mellon Matching	10,902,291
Astronomy Funds	8,526,446
Anonymous Matching	8,354,511
Anonymous	7,667,540
Wood	5,725,007
Golden	3,744,883
Carnegie Futures	3,545,561
Bowen	2,640,797
Colburn	2,105,158
Science Education Fund	2,065,466
McClintock Fund	1,746,760
Special Instrumentation	1,225,207
Bush Bequest	1,140,889
Moseley Astronomy	828,809
Special Opportunities	814,542
Starr Fellowship	803,069
Roberts	448,306
Lundmark	343,677
Morgenroth	258,931
Hollaender	258,445
Forbush	147,507
Moseley	147,348
Bush	119,969
Green Fellowship	115,288
Hale	108,092
Harkavy	105,931
Endowed Fellowships	5,000
Total	$507,443,374

Financial Statements
for the year ended June 30, 2002

Independent Auditors' Report

***To the Audit Committee of the
Carnegie Institution of Washington:***

We have audited the accompanying statements of financial position of the Carnegie Institution of Washington (Carnegie) as of June 30, 2002 and 2001, and the related statements of activities and cash flows for the years then ended. These financial statements are the responsibility of Carnegie's management. Our responsibility is to express an opinion on these financial statements based on our audits.

We conducted our audits in accordance with auditing standards generally accepted in the United States of America. Those standards require that we plan and perform the audit to obtain reasonable assurance about whether the financial statements are free of material misstatement. An audit includes examining, on a test basis, evidence supporting the amounts and disclosures in the financial statements. An audit also includes assessing the accounting principles used and significant estimates made by management, as well as evaluating the overall financial statement presentation. We believe that our audits provide a reasonable basis for our opinion.

In our opinion, the financial statements referred to above present fairly, in all material respects, the financial position of the Carnegie Institution of Washington as of June 30, 2002 and 2001, and its changes in net assets and its cash flows for the years then ended, in conformity with accounting principles generally accepted in the United States of America.

Our audits were made for the purpose of forming an opinion on the basic financial statements taken as a whole. The supplementary information included in Schedule 1 is presented for purposes of additional analysis and is not a required part of the basic financial statements. Such information has been subjected to the auditing procedures applied in the audits of the basic financial statements and, in our opinion, is fairly presented in all material respects in relation to the basic financial statements taken as a whole.

KPMG LLP

October 25, 2002

Statements of Financial Position

June 30, 2002 and 2001

Assets	2002	2001
Cash and cash equivalents	$ 177,964	1,370,838
Accrued investment income	76,768	123,789
Contributions receivable, net (note 2)	6,877,761	10,042,248
Accounts receivable and other assets	6,122,068	4,188,572
Bond proceeds held by trustee (note 6)	83	392
Investments (note 3)	507,443,374	517,305,413
Construction in progress (notes 4 and 5)	40,281,812	34,026,765
Property and equipment, net (note 4)	86,698,819	87,165,558
Total assets	**$ 647,678,649**	**654,223,575**

Liabilities and Net Assets		
Accounts payable and accrued expenses	$ 3,975,669	5,676,804
Deferred revenue (note 5)	34,810,393	33,048,536
Bonds payable (note 6)	34,953,919	34,917,054
Accrued postretirement benefits (note 7)	10,636,000	10,497,000
Total liabilities	84,375,981	84,139,394
Net assets (note 8):		
Unrestricted:		
Board designated:		
Invested in fixed assets, net	57,216,319	53,226,733
Designated for managed investments	440,440,733	452,200,043
Undesignated	4,398,917	5,238,854
	502,055,969	510,665,630
Temporarily restricted	23,453,842	21,655,218
Permanently restricted	37,792,857	37,763,333
Total net assets	563,302,668	570,084,181
Commitments, contingencies, and subsequent event (notes 9 through 13)		
Total liabilities and net assets	**$ 647,678,649**	**654,223,575**

See accompanying notes to financial statements.

Statements of Activities

Years ended June 30, 2002 and 2001

	2002				2001			
	Unrestricted	Temporarily restricted	Permanently restricted	Total	Unrestricted	Temporarily restricted	Permanently restricted	Total
Revenues and support:								
External revenue:								
Grants and contracts	$ 20,514,020	—	—	20,514,020	18,210,545	—	—	18,210,545
Contributions and gifts	1,137,470	2,469,655	11,688	3,618,813	9,112,683	4,469,725	2,673	13,585,081
Net gain (loss) on disposals of property	(61,147)	—	—	(61,147)	19,449	—	—	19,449
Other income	2,117,228	—	—	2,117,228	1,211,623	—	—	1,211,623
Net external revenue	23,707,571	2,469,655	11,688	26,188,914	28,554,300	4,469,725	2,673	33,026,698
Investment income (note 3)	14,451,779	781,810	17,836	15,251,425	49,106,316	2,475,765	56,804	51,638,885
Net assets released from restrictions and clarification of donor intent (note 8)	1,452,841	(1,452,841)	—	—	2,865,906	(2,865,906)	—	—
Total revenues, gains, and other support	39,612,191	1,798,624	29,524	41,440,339	80,526,522	4,079,584	59,477	84,665,583
Expenses:								
Program and supporting services expenses:								
Terrestrial Magnetism	7,467,442	—	—	7,467,442	7,238,422	—	—	7,238,422
Observatories	8,562,433	—	—	8,562,433	7,819,566	—	—	7,819,566
Geophysical Laboratory	9,463,055	—	—	9,463,055	8,039,808	—	—	8,039,808
Embryology	6,195,323	—	—	6,195,323	6,421,919	—	—	6,421,919
Plant Biology	9,592,810	—	—	9,592,810	7,864,699	—	—	7,864,699
Other Programs	1,763,724	—	—	1,763,724	1,121,442	—	—	1,121,442
Administrative and general expenses	5,177,065	—	—	5,177,065	3,648,399	—	—	3,648,399
Total expenses	48,221,852	—	—	48,221,852	42,154,255	—	—	42,154,255
Increase (decrease) in net assets	(8,609,661)	1,798,624	29,524	(6,781,513)	38,372,267	4,079,584	59,477	42,511,328
Net assets at the beginning of the year	510,665,630	21,655,218	37,763,333	570,084,181	472,293,363	17,575,634	37,703,856	527,572,853
Net assets at the end of the year	$ 502,055,969	23,453,842	37,792,857	563,302,668	510,665,630	21,655,218	37,763,333	570,084,181

See accompanying notes to financial statements.

Statements of Cash Flows

Years ended June 30, 2002 and 2001

	2002	2001
Cash flows from operating activities:		
Increase (decrease) in net assets	$ (6,781,513)	42,511,328
Adjustments to reconcile increase (decrease) in net assets to net cash used for operating activities:		
Depreciation	4,700,801	3,998,855
Net gains on investments	(6,760,930)	(39,212,556)
Contributions of stock	(2,467,969)	(915,587)
Loss (gain) on disposal of property	61,147	(19,449)
Amortization of bond issuance costs and discount	36,865	36,864
(Increase) decrease in assets:		
Receivables	1,230,991	(7,875,710)
Accrued investment income	47,021	(1,410)
Increase (decrease) in liabilities:		
Accounts payable and accrued expenses	(1,701,135)	1,100,575
Deferred revenue	1,761,857	(28,073)
Accrued postretirement benefits	139,000	176,168
Contributions and investment income restricted for long-term investment	(1,891,271)	(3,346,804)
Net cash used for operating activities	(11,625,136)	(3,575,799)
Cash flows from investing activities:		
Draws from bond proceeds held by trustee	309	213,992
Acquisition of property and equipment	(4,304,605)	(3,176,542)
Construction of telescope, facilities, and equipment	(6,255,047)	(8,314,728)
Investments purchased	(234,823,334)	(187,658,065)
Proceeds from investments sold or matured	253,914,272	197,672,437
Proceeds from sale of property and equipment	9,396	49,236
Net cash provided by (used for) investing activities	8,540,991	(1,213,670)
Cash flows from financing activities:		
Proceeds from contributions and investment income restricted for:		
Investment in endowment	1,576,148	366,540
Investment in property and equipment	315,123	2,980,264
Net cash provided by financing activities	1,891,271	3,346,804
Net decrease in cash and cash equivalents	(1,192,874)	(1,442,665)
Cash and cash equivalents at the beginning of the year	1,370,838	2,813,503
Cash and cash equivalents at the end of the year	$ 177,964	1,370,838
Supplementary cash flow information:		
Cash paid for interest	$ 1,404,797	1,397,188
Non-cash activity–contributions of stock	2,467,969	915,587

See accompanying notes to financial statements.

Notes to Financial Statements

June 30, 2002 and 2001

(1) Organization and Summary of Significant Accounting Policies

Organization

The Carnegie Institution of Washington (Carnegie) conducts advanced research and training in the sciences. It carries out its scientific work in five research centers located throughout the United States and at an observatory in Chile. The centers are the Departments of Embryology, Plant Biology, and Terrestrial Magnetism, the Geophysical Laboratory, and the Observatories. Income from investments represents approximately 37% and 61% of Carnegie's total revenues for the years ended June 30, 2002 and 2001, respectively. Carnegie's other income is mainly from gifts and federal grants and contracts.

Basis of Accounting and Presentation

The financial statements are prepared on the accrual basis of accounting. Contributions and gifts revenues are classified according to the existence or absence of donorimposed restrictions. Also, satisfaction of donor-imposed restrictions are reported as releases of restrictions in the statements of activities.

Investments and Cash Equivalents

Carnegie's debt and equity investments are reported at their fair values based on quoted market prices. Carnegie reports investments in limited partnerships at fair value as determined and reported by the general partners. All changes in fair value are recognized in the statements of activities. Carnegie considers all highly liquid debt instruments purchased with remaining maturities of 90 days or less to be cash equivalents. Money market and other highly liquid instruments held by investment managers are reported as investments.

Income Taxes

Carnegie is exempt from federal income tax under Section 501(c)(3) of the Internal Revenue Code (the Code) except for amounts from unrelated business income. No provision for income taxes is reflected in the accompanying financial statements since amounts of unrelated business are immaterial. Carnegie is also an educational institution within the meaning of Section 170(b)(1)(A)(ii) of the Code. The Internal Revenue Service has classified Carnegie as other than a private foundation, as defined in Section 509(a) of the Code.

Fair Value of Financial Instruments

Financial instruments of Carnegie include cash equivalents, receivables, investments, bond proceeds held by trustee, accounts and broker payables, and bonds payable. The fair value of investments in debt and equity securities is based on quoted market prices. The fair value of investments in limited partnerships is based on information provided by the general partners.

The fair value of Series A bonds payable is based on quoted market prices. The fair value of Series B bonds payable is estimated to be the carrying value, since these bonds bear adjustable market rates (see note 6).

The fair values of cash equivalents, receivables, bond proceeds held by trustee, and accounts and broker payables approximate their carrying values based on their short maturities.

Use of Estimates

The preparation of financial statements in conformity with accounting principles generally accepted in the United States of America requires management to make estimates and assumptions that affect the reported amounts of assets and liabilities and disclosure of contingent assets and liabilities at the date of the financial statements. They also affect the reported amounts of revenues and expenses during the reporting period. Actual results could differ from those estimates.

Property and Equipment

Carnegie capitalizes at cost expenditures for land, buildings and leasehold improvements, telescopes, scientific and administrative equipment, and projects in progress. Routine replacement, maintenance, and repairs are charged to expense.

Depreciation is computed on a straight-line basis, generally over the following estimated useful lives:

Buildings and telescopes	50 years
Leasehold improvements	lesser of 25 years or the remaining term of the lease
Scientific and administrative equipment	2-10 years, based on scientific life of equipment

Contributions

Contributions are classified based on the existence or absence of donor-imposed restrictions. Contributions and net assets are classified as follows:

Unrestricted – includes all contributions received without donor-imposed restrictions on use or time.

Temporarily restricted – includes contributions with donor-imposed restrictions as to purpose of gift and/or time period expended.

Permanently restricted – generally includes endowment gifts in which donors stipulated that the corpus be invested in perpetuity. Only the investment income generated from endowments may be spent. Certain endowments require that a portion of the investment income be reinvested in perpetuity.

Contributions to be received after one year are discounted at an appropriate discount rate commensurate with the risks involved. Amortization of the discount is recorded as additional revenue and used in accordance with donor-imposed restrictions, if any.

Gifts of long-lived assets, such as buildings or equipment, are considered unrestricted when placed in service. Cash gifts restricted for investment in long-lived assets are released from restriction when the asset is acquired or as costs are incurred for asset construction.

Grants

Carnegie records revenues on grants from federal agencies only to the extent that reimbursable expenses are incurred. Accordingly, funds received in excess of reimbursable expenses are recorded as deferred revenue, and expenses in excess of reimbursements are recorded as accounts receivable. Reimbursement of indirect costs is based upon provisional rates which are subject to subsequent audit by Carnegie's federal cognizant agency, the National Science Foundation.

Allocation of Costs

The costs of providing programs and supporting services have been summarized in the statements of activities. Accordingly, certain costs have been allocated among the programs and supporting services benefited. Fundraising expenses of $583,951 and $416,545 for the years ended June 30, 2002 and 2001, respectively, have been included in administrative and general expenses.

(2) Contributions Receivable

Contributions receivable representing unconditional promises expected to be collected are summarized as follows at June 30, 2002 and 2001:

Years ending June 30,	2002	2001
2002	$ —	3,333,538
2003	2,851,095	3,277,126
2004	2,110,305	2,631,075
2005	1,756,853	1,654,000
2006	631,685	601,000
2007	1,000	17,653
	7,350,938	11,514,392
Less discount to present value	(473,177)	(1,472,144)
	$6,877,761	**10,042,248**

Pledges receivable as of June 30, 2002 and 2001, were discounted using the 3-year U.S. Treasury rate, which was approximately 3.4% and 6.0%, respectively.

(3) Investments

At June 30, 2002 and 2001, investments at fair value consisted of the following:

	2002	2001
Time deposits and money market funds	$ 16,406,227	23,826,461
Debt mutual funds	248,511	576,479
Debt securities	123,090,148	120,546,768
Equity securities	146,148,319	161,841,511
Limited real estate partnerships	55,951,123	50,388,134
Limited partnerships	165,599,046	160,126,060
	$ 507,443,374	**517,305,413**

Investment income, net, for the years ended June 30, 2002 and 2001, consisted of the following:

	2002	2001
Interest and dividends	$ 9,622,175	13,529,083
Net realized gains	17,131,992	13,059,770
Net unrealized (losses) gains	(10,371,062)	26,152,786
Less investment management expenses	(1,131,680)	(1,102,754)
	$ 15,251,425	**51,638,885**

As of June 30, 2002, the fair value for approximately $92.3 million of Carnegie's $222 million of real estate and limited partnership investments has been estimated by the general partners in the absence of readily ascertainable values as of that date. However, these estimated fair values may differ from the values that would have been used had a ready market existed. As of June 30, 2001, the fair value for approximately $80 million of Carnegie's $210 million of real estate and limited partnership investments had been estimated.

(4) Property and Equipment

At June 30, 2002 and 2001, property and equipment placed in service consisted of the following:

	2002	2001
Buildings and improvements	$ 44,926,389	44,397,020
Scientific equipment	23,645,798	21,559,202
Telescopes	50,434,811	49,618,468
Administrative equipment	2,859,168	2,803,185
Land	787,896	787,896
Art	40,192	40,192
	122,694,254	119,205,963
Less accumulated depreciation	(35,995,435)	(32,040,405)
	$ 86,698,819	**87,165,558**

At June 30, 2002 and 2001, construction in progress consisted of the following:

	2002	2001
Telescope	$ 28,789,669	26,506,416
Buildings	1,009,249	398,602
Scientific equipment	10,482,894	7,121,747
	$ 40,281,812	**34,026,765**

At June 30, 2002 and 2001, approximately $82 million and $78 million, respectively, of construction in progress and other property, net of accumulated depreciation, was located in Las Campanas, Chile. During 2002 and 2001, Carnegie capitalized interest costs (net of interest earned of $85 and $3,200, respectively) of approximately $1,344,000 and $1,596,000, respectively, as construction in progress.

(5) Magellan Consortium

During the year ended June 30, 1998, Carnegie entered into an agreement (Magellan Agreement) with four universities establishing a consortium to build and operate the Magellan telescopes. The two

Magellan telescopes are located on Manqui Peak, Las Campanas in Chile. The first telescope, with a cost of approximately $41,708,000, was placed in service during 2001 while the other continues to be built. The total construction cost of the two telescopes is expected to be approximately $72 million and the telescopes are recorded as assets by Carnegie. Title to the Magellan facilities is held by Carnegie. As of June 30, 2002, construction in progress of $28,789,669 related to the Magellan project.

The university members of the consortium, by contribution to the construction and operating costs of Magellan, acquire rights of access and oversight as described in the Magellan Agreement. Total contributions by the university members for construction are expected to cover 50% of the total expected costs. As of June 30, 2002, $34,252,000 has been received. These monies are being used by Carnegie to finance part of the Magellan Telescopes' construction costs. As of June 30, 2002 and 2001, the excess of university members contributions over operating costs totaled $32,235,751 and $32,285,383, respectively, and is included in deferred revenue in the accompanying statements of financial position. The deferred revenue is being recognized ratably as income over the remaining estimated useful lives of the telescopes.

(6) Bonds Payable

On November 1, 1993, Carnegie issued $17.5 million each of Series A and Series B California Educational Facilities Authority Revenue taxexempt bonds. Bond proceeds were used to finance the Magellan telescope project and the renovation of the facilities of the Observatories at Pasadena. The balances outstanding at June 30, 2002 and 2001, on the Series A issue totaled $17,471,444 and $17,448,600, respectively, and on the Series B issue totaled $17,482,475 and $17,468,454, respectively. The balances outstanding are net of unamortized bond issue costs and bond discount. Bond proceeds held by the trustee and unexpended at June 30, 2002 and 2001, totaled $83 and $392, respectively.

Series A bonds bear interest at 5.6% payable in arrears semiannually on each April 1 and October 1 and upon maturity on October 1, 2023. Series B bonds bear interest at variable money market rates (ranging from 1.10% to 3.00% at June 30, 2002) in effect from time to time, up to a maximum of 12% over the applicable money market rate period of between 1 and 270 days and have a stated maturity of October 1, 2023. At the end of each money market rate period, Series B bondholders are required to offer the bonds for repurchase at the applicable money market rate. When repurchased, the Series B bonds are resold at the current applicable money market rate and for a new rate period.

Carnegie is not required to repay the Series A and B bonds until the October 1, 2023, maturity date, and Carnegie has the intent and the ability to effect the purchase and resale of the Series B bonds through a tender agent; therefore, all bonds payable are classified as long term. Sinking fund redemptions begin in 2019 in installments for both series. The fair value of Series A bonds payable at June 30, 2002 and 2001, based on quoted market prices is estimated at $18,325,000 and $18,417,000, respectively. The fair value of Series B bonds payable at June 30, 2002 and 2001, is estimated to approximate carrying value as the mandatory tender dates on which the bonds are repriced are generally within three months of year end.

(7) Employee Benefit Plans

Retirement Plan

Carnegie has a noncontributory, defined contribution, money-purchase retirement plan in which all U.S. personnel are eligible to participate. After one year's participation, an individual's benefits are fully vested. The Plan has been funded through individually owned annuities issued by Teachers' Insurance and Annuity Association (TIAA) and College Retirement Equities Fund (CREF). Contributions made by Carnegie totaled approximately $2,800,000 and $2,458,000 for the years ended June 30, 2002 and 2001, respectively.

Postretirement Benefits Plan

Carnegie provides postretirement medical benefits to all employees who retire after age 55 and have at least 10 years of service. Cash payments made by Carnegie for these benefits totaled approximately $635,000 and $454,000 for the years ended June 30, 2002 and 2001, respectively.

The expense for postretirement benefits for the years ended June 30, 2002 and 2001, consists of the following:

	2002	2001
Service cost – benefits earned during the year	$ 340,000	285,000
Interest cost on projected benefit obligation	554,000	515,000
Amortization of gain	(120,000)	(170,000)
Postretirement benefit cost	**$ 774,000**	**630,000**

The 2002 postretirement benefits expense was approximately $139,000 more than the cash expense of $635,000, and the 2001 postretirement benefits expense was approximately $176,000 more than the cash expense of $454,000. The postretirement benefits expense was allocated among program and supporting services expenses in the statements of activities.

The reconciliation of the Plan's funded status to amounts recognized in the financial statements at June 30, 2002 and 2001, follows:

	2002	2001
Change in benefit obligation:		
Benefit obligation at beginning of year	$ 7,572,000	6,606,000
Service cost	340,000	285,000
Interest cost	554,000	515,000
Actuarial loss	2,469,000	620,000
Benefits paid	(635,000)	(454,000)
Benefit obligation at end of year	10,300,000	7,572,000
Change in plan assets:		
Fair value of plan assets at beginning of year	—	—
Actual return on plan assets	—	—
Contribution to plan	635,000	454,000
Benefits paid	(635,000)	(454,000)
Fair value of plan assets at end of year	—	—
Funded status	(10,300,000)	(7,572,000)
Unrecognized net actuarial gain	(336,000)	(2,925,000)
Accrued benefit cost	$ (10,636,000)	(10,497,000)

The present value of the benefit obligation as of June 30, 2002, was determined using an assumed health care cost trend rate of 12.0% and an assumed discount rate of 7.3%. The present value of the benefit obligation as of June 30, 2001, was determined using an assumed health care cost trend rate of 8.4% and an assumed discount rate of 7.5%. Carnegie's policy is to fund postretirement benefits as claims and administrative fees are paid.

For measurement purposes, an 8.39% annual rate of increase in the per capita cost of covered health care benefits was assumed for 2002; the rate was assumed to decrease gradually to 5.50% in 10 years and remain at that level thereafter. The health care cost trend rate assumption has a significant effect on the amounts reported. A one percentage point change in assumed annual health care cost trend rate would have the following effects:

	One-percentage point increase	One-percentage point decrease
Effect on total of service and interest cost components	$ 196,000	(150,000)
Effect on postretirement benefit obligation	1,570,000	(1,268,000)

(8) Net Assets

At June 30, 2002 and 2001, temporarily restricted net assets were available to support the following donor-restricted purposes:

	2002	2001
Specific research programs	$ 14,195,484	16,060,208
Equipment acquisition and construction	3,452,955	5,595,010
Passage of time	5,805,403	—
	$ 23,453,842	**21,655,218**

At June 30, 2002 and 2001, permanently restricted net assets consisted of permanent endowments, the income from which is available to support the following donor-restricted purposes:

	2002	2001
Specific research programs	$ 14,588,138	14,558,614
Equipment acquisition and construction	1,204,719	1,204,719
General support (Carnegie endowment)	22,000,000	22,000,000
	$ 37,792,857	**37,763,333**

During 2002 and 2001, Carnegie met donor-imposed requirements on certain gifts and received clarifications from donors about the intention of their gifts and, therefore, released temporarily restricted net assets as follows:

	2002	2001
Specific research programs	$ 3,737,082	2,406,098
Equipment acquisition and construction	2,639,406	459,808
Passage of time	2,682,126	—
Clarification of donor intent	(7,605,773)	—
	$ 1,452,841	**2,865,906**

(9) Federal Grants and Contracts

Costs charged to the federal government under cost reimbursement grants and contracts are subject to government audit. Therefore, all such costs are subject to adjustment. Management believes that adjustments, if any, would not have a significant effect on the financial statements.

(10) Commitments

Carnegie entered into a contract with the University of Arizona for the construction of the primary mirror and support system for the second telescope in the Magellan project. The amount of the contract is approximately $9,700,000 all of which had been incurred at June 30, 2002. Carnegie also has other contracts relating to the construction of Magellan with outstanding commitments totaling approximately $646,000.

Carnegie has outstanding commitments to invest approximately $59 million in limited partnerships.

(11) Lease Arrangements

Carnegie leases a portion of the land it owns in Las Campanas, Chile, to other organizations. These organizations have built and operate telescopes on the land. Most of the lease arrangements are not specific and some are at no cost to the other organizations. One of the lease arrangements is noncancelable and had annual rent of approximately $160,000 and $131,000 for fiscal years 2002 and 2001, respectively. For the no-cost leases, the value of the leases could not be determined and is not considered significant and, accordingly,

contributions have not been recorded in the financial statements.

Carnegie also leases a portion of one of its laboratories to another organization for an indefinite term. Rents to be received under the agreement are approximately $496,000 annually, adjusted for CPI increases.

Carnegie leases land and buildings. The monetary terms of the leases are considerably below fair value, however, these terms were developed considering other nonmonetary transactions between Carnegie and the lessors. The substance of the transactions indicates arms-length terms between Carnegie and the lessors. The monetary value of the leases could not be determined and has not been recorded in the financial statements

(12) Subsequent Event—Construction and Financing of Embryology Building

In October 2002, Carnegie issued $30 million of Maryland Health and Higher Education Facilities Authority Revenue Bonds. Proceeds generated by the sale of these bonds will be used to build a new facility for Carnegie's Department of Embryology on the Johns Hopkins Homewood Campus in Baltimore, Maryland. The Bonds may bear interest as a Daily, Weekly, Commercial Paper or Term Rate as selected by the Authority, at the request of Carnegie, provided that in no event shall the Daily, Weekly, Commercial Paper or Term Rate exceed 12% per annum. The interest on each bond shall be due and payable on the Interest Payment Date for such Bond, and on each Redemption Date and on the date of any acceleration prior thereto. Carnegie's intention is to enter into an interest rate swap for approximately one-half of the face value of the bonds at the time of issuance, in order to obtain favorable fixed-rate terms. Sinking fund redemptions begin on October 1, 2033, and occur each October 1 through 2037.

Carnegie plans to sign a long-term ground lease for the site selected for the new facility, as well as a Development Services Agreement, whereby Johns Hopkins University will provide full construction management services to Carnegie. Carnegie will hold title to the Maxine F. Singer Building, once it is completed. The current facility used by the Embryology Department is owned by Johns Hopkins University, which will regain the use of the building once the Embryology Department staff and experiments have been successfully transitioned to the Singer Building.

(13) Contingencies

In 1999, Carnegie notified the National Science Foundation (NSF) of its discovery of inappropriate expenditures made under one of its grants to Carnegie. In 2002, NSF began an investigation of these expenditures. The investigation is ongoing, and its results are unknown, however the NSF estimates the potential amount to be repaid by Carnegie to be between $0 and $300,000. Management believes that the result of the investigation will not have a material adverse effect on the financial statements.

(14) Related Party Transactions

Carnegie recorded contributions from its trustees, officers and directors of $1,228,195 and $10,258,293, for the years ended June 30, 2002 and 2001, respectively.

Schedule of Expenses

Schedule 1

Years ended June 30, 2002 and 2001

	2002			2001		
	Carnegie funds	Federal and private grants	Total expenses	Carnegie funds	Federal and private grants	Total expenses
Personnel costs:						
Salaries	$ 14,957,846	4,938,335	19,896,181	12,816,467	4,624,046	17,440,513
Fringe benefits and payroll taxes	4,818,312	1,392,338	6,210,650	3,912,937	1,261,398	5,174,335
Total personnel costs	19,776,158	6,330,673	26,106,831	16,729,404	5,885,444	22,614,848
Fellowship grants and awards	1,486,946	760,633	2,247,579	1,500,162	588,585	2,088,747
Depreciation	4,700,801	—	4,700,801	3,998,855	—	3,998,855
General expenses:						
Educational and research supplies	1,670,969	4,041,028	5,711,997	1,481,157	3,882,931	5,364,088
Building maintenance and operation	2,336,183	575,179	2,911,362	2,306,653	535,549	2,842,202
Travel and meetings	1,119,553	413,802	1,533,355	1,136,927	479,217	1,616,144
Publications	43,937	95,801	139,738	48,218	50,292	98,510
Shop	160,851	2	160,853	169,243	16,791	186,034
Telephone	187,242	10,360	197,602	190,580	13,295	203,875
Books and subscriptions	295,298	390	295,688	289,686	—	289,686
Administrative and general	1,479,605	253,462	1,733,067	769,077	112,293	881,370
Printing and copying	60,807	—	60,807	202,555	—	202,555
Shipping and postage	189,010	13,479	202,489	179,520	21,597	201,117
Insurance, taxes, and professional fees	1,698,210	108,970	1,807,180	1,067,029	122,377	1,189,406
Equipment	2,282,630	2,552,393	4,835,023	2,172,131	1,450,468	3,622,599
Fund-raising expense	516,855	—	516,855	349,449	—	349,449
Total general expenses	12,041,150	8,064,866	20,106,016	10,362,225	6,684,810	17,047,035
Total direct costs	38,005,055	15,156,172	53,161,227	32,590,646	13,158,839	45,749,485
Indirect costs:						
Grants and contracts	(5,357,848)	5,357,848	—	(5,051,706)	5,051,706	—
Total costs	32,647,207	20,514,020	53,161,227	27,538,940	18,210,545	45,749,485
Capitalized scientific equipment	(2,813,180)	(2,126,195)	(4,939,375)	(2,301,093)	(1,294,137)	(3,595,230)
Total expenses	**$ 29,834,027**	**18,387,825**	**48,221,852**	**25,237,847**	**16,916,408**	**42,154,255**

See accompanying independent auditors' report.

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For additional information, please see the Carnegie website at www.CarnegieInstitution.org/externalaffairs or call Linda Feinberg in the Office of External Affairs, 202.939.1141, or write:

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